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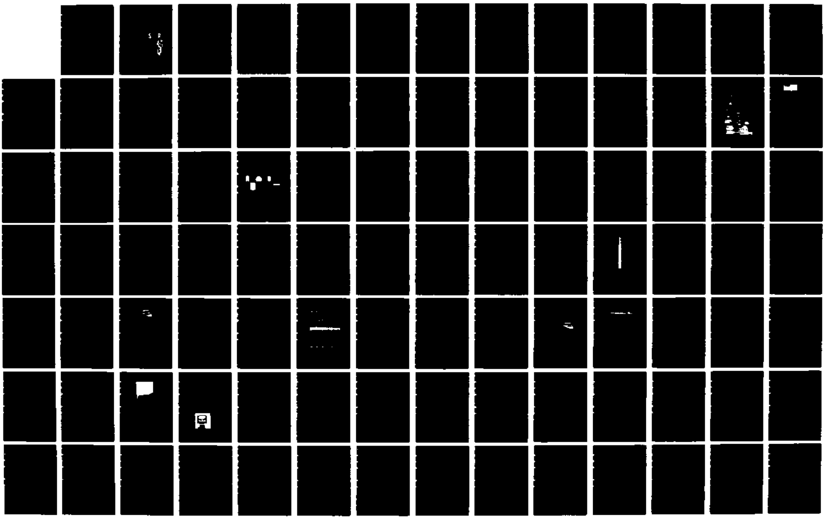

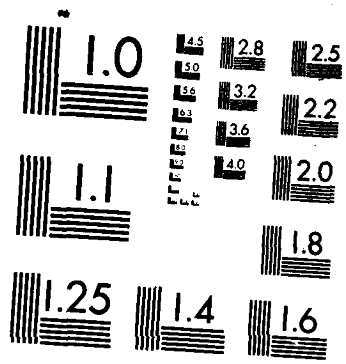


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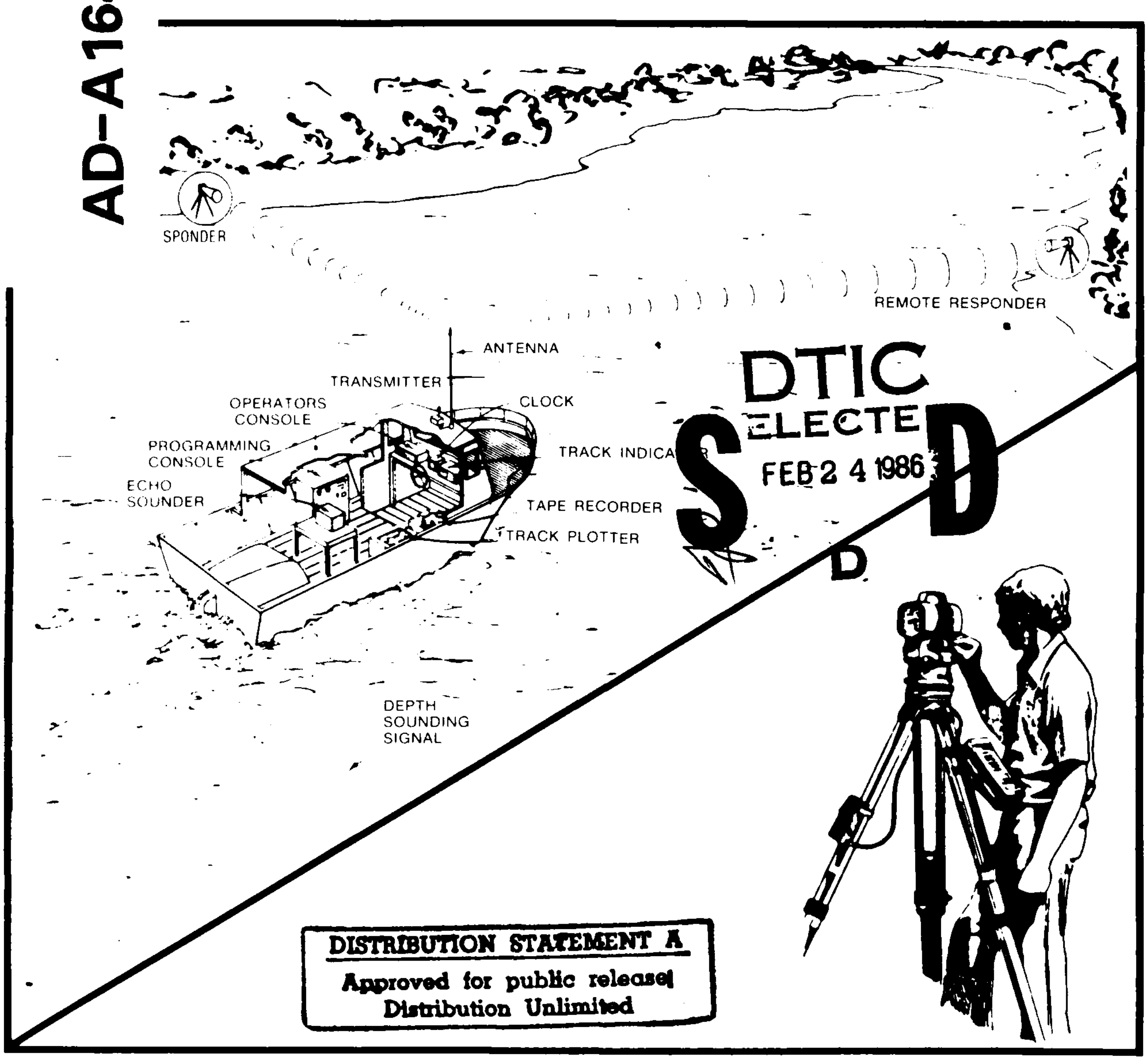
U.S. Army Corps of Engineers

# SURVEYING CONFERENCE

4-8 February 1985




February 1985

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

U. S. Army Corps of Engineers

# SURVEYING CONFERENCE

4-8 February 1985

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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
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## FOREWORD

This publication summarizes the proceedings of the Corps Surveying Requirements Meeting held at the Jacksonville Hilton Hotel, Jacksonville, Florida, on 4-8 February 1985. The meeting which combined land and hydrographic surveying was held to encourage a continuing exchange of ideas, methods, and experiences of District surveying personnel. The experience and knowledge thus gained will be beneficial to the Corps surveying improvement objectives.

The meeting was sponsored by the Office, Chief of Engineers, under the Surveying and Mapping Program of the Surveying and Satellite Applications Research Area. The objective of the research program is to ensure effective and efficient surveying systems and methods for Corps use.

These proceedings were compiled by Messrs. E. D. Hart and T. L. Fagerburg of the Hydraulics Laboratory (HL), and Mr. G. C. Downing of the Instrumentation Services Division (ISD) under the general supervision of Mr. M. B. Boyd, Chief, Hydraulic Analysis Division, HL, Mr. F. A. Herrmann, Chief, HL, and Mr. G. P. Bonner, Chief, ISD, U. S. Army Engineer Waterways Experiment Station (WES).

COL Robert C. Lee, CE, was Commander and Director of WES during the period of the meeting and preparation of the proceedings. Mr. F. R. Brown was Technical Director.

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SESSION XI: PHOTOGRAMMETRY



PERSONNEL AND EQUIPMENT

# AGENDA

**TUESDAY - 5 FEBRUARY (Open to the Public)**

OFFICAL CONFERENCE OPENING

| | |
|---|---|
| 8:00 am | 1. Administrative Remarks - Ed East, Conference Co-Chairman |
| 8:10 am | 2. Welcoming - Colonel Charles T. Myers, III, District Engineer, Jacksonville District |
| 8:25 am | 3. ACSM/NSPS Remarks - William G. Wallace, Jr., ACSM Board of Directors, and P. Porcher Gregg, NSPS President |
| 8:40 am | 4. Key Note Address - Lloyd A. Duscha, Deputy Director, Engineering & Construction Directorate, Office of Chief of Engineers, U.S. Army Corps of Engineers |
| 9:30 am | BREAK |
| | TECHNICAL SESSION 1 (Hydrographic Equipment Developments) |
| 10:00 am | 1. Session Overview - George Downing, WES, Chairman |
| 10:05 am | 2. New Digital Signal Processing Techniques as an Aid to Hydrographic and Dredging Surveys - David Caulfield, Caulfield Engineering |
| 10:20 am | 3. The Next Generation Survey Echo Sounder - Erik Nielsen, Navitronics AS |
| 10:35 am | 4. Small Boat Survey System - Barry McLeave, WES |
| 10:50 am | 5. Swell Compensator - Juris Jursions, Portland District |
| 11:05 am | 6. General Discussions - Chairman and Panel Members |
| 11:30 am | LUNCH |
| | TECHNICAL SESSION 2 (Hydrographic Sweep Systems and Vessel Design) |
| 1:30 pm | 1. Session Overview - Carl Lamphere, Detroit District, Chairman |
| 1:40 pm | 2. Detroit District Multi-Transducer Survey Sweep System, Brian F. Apsey, Odom Offshore Surveys, Inc. |
| 1:55 pm | 3. Automated Sweep Surveys- Wayne Ross, Ross Laboratories, Inc. |
| 2:10 pm | 4. SWATH Vessel - Jack Bechley, Portland District |
| 2:25 pm | 5. SEACO SWATH Vessel - Scott Drummond, SEACO, Inc. |
| 2:40 pm | 6. General Disscussions - Chairman and Panel Members |
| 3:00 pm | BREAK |
| | TECHNICAL SESSION 3 (Beach and Nearshore Surveys) |
| 3:30 pm | 1. Session Overview - Dale Hart, WES, Chairman |
| 3:35 pm | 2. Field Comparison of Four Beach and Nearshore Survey Systems - Jim Clausner, WES |
| 3:55 pm | 3. Surf Zone and Nearshore Surveying with Helicopter and a Total Station - Robert Craig and Willard Teem, Portland District |
| 4:15 pm | 4. A Method for Adjusting Beach Profile Lines for Offshore Closure - Norman H. Beumel, Coastal Planning and Engineering |
| 4:35 pm | 5. General Discussions - Chairman and Panel Members |
| 5:00 pm | END OF SESSION |

WEDNESDAY - 6 FEBRUARY (Open to the Public)

TECHNICAL SESSION 4
(Tides)

| | | |
|---|---|---|
| 8:00 am | 1. | Session Overview - Eugene Batty, Norfolk District, Chairman |
| 8:05 am | 2. | Tidal Datums and their Uses/A Summary - James R. Hubbard, NOS, NOAA |
| 8:20 am | 3. | Tidal Corrections from a Dredging Contractor's Perspective - Rick Smith, T.L. James and Company |
| 8:30 am | 4. | Application of Water Level Data to Sounding Reducers - Joseph Mullins, NOS, NOAA |
| 8:45 am | 5. | Operational Experience and Intercomparison of Bubbler Gauges and Pressure Transducers - Morgan Wolaver, Itech, LTD. |
| 8:55 am | 6. | NOS Next Generation Water Level Measurement System - Wolfgang Scherer, NOS, NOAA |
| 9:15 am | 7. | General Disccusions - Chairman and Panel Members |
| 9:30 am | | BREAK |

TECHNICAL SESSION 5
(Hydrographic Positioning Systems and Data Processing)

| | | |
|---|---|---|
| 10:00 am | 1. | Session Overview - Glen Boone, Wilmington Dist., Chairman |
| 10:05 am | 2. | A Portable Acoustic Navigation System for Hydrographic Surveys - Dave Porta, Datasonics, Inc. |
| 10:20 am | 3. | Navigation Software with On-Line Quality Control for Small Vessel Operations - Timothy Hoelzle, Itech, LTD |
| 10:35 am | 4. | Hydrographic Data Processing Using the HP 200 - Ray Bhutaba, Comstar, Inc. |
| 10:50 am | 5. | Parallel Line Surveying - Jack Bechley, Portland District |
| 11:05 am | 6. | The Adaptation of Traditional Hydrographic Techniques to Precise Dredge Survey - Colin Weeks, Hydrographic Associates, Inc. |
| 11:20 am | 7. | General Discussions - Chairman and Panel Members |
| 11:30 am | | LUNCH |

TECHNICAL SESSION 6
(Remote Sensing (RS))

| | | |
|---|---|---|
| 1:30 pm | 1. | Session Overview - Ed East, OCE, Chairman |
| 1:35 pm | 2. | RS: A Valuable Tool for the Corps, Bob Plott, OCE |
| 1:50 pm | 3. | Data Collection; RS/Surveying & Mapping - Dave Licky, WRSC-C |
| 2:05 pm | 4. | Remote Sensing Research and Applications, Ike McKin, CRREL |
| 2:20 pm | 5. | North Central Division's Remote Sensing Applications to Surveying & Mapping - Zane Goodwin, NCD |
| 2:35 pm | 6. | Airborne Programable Imaging Spectrometer for Shallow Water Digital Mapping - A.B. Hollinger, Moniteq, LTD. |
| 2:50 pm | 7. | General Discussions - Chairman and Panel Members |
| 3:00 pm | | BREAK |

TECHNICAL SESSION 7
(Control - Datums, Benchmarks, and Land Survey Systems)

| | | |
|---|---|---|
| 3:30 pm | 1. | Session Overview - Don Eames, New Orleans District, Chairman |
| 3:35 pm | 2. | North American Datum (NAD) Update - Steve Vogel, NGS, C&GS, NOS, NOAA |
| 3:50 pm | 3. | North American Vertical Datum (NAVD) Update - David Zilkoski, NGS, C&GS, NOS, NOAA |
| 4:05 pm | 4. | Vertically- Stable Benchmarks: A Synthesis of Existing Information - Lawrence Gatto, CRREL |
| 4:20 pm | 5. | General Discussions - Chairman and Panel Members |
| 5:00 pm | | END OF SESSION |

THURSDAY - 7 FEBRUARY (Open to the Public)

TECHNICAL SESSION 8
(Topographic Equipment Development)

| | | |
|---|---|---|
| 8:00 am | 1. | Session Overview - Kevin Logan, ETL, Chairman |
| 8:05 am | 2. | Determining an Azimuth with a North Seeking Gyro - Kevin Logan, ETL |
| 8:25 am | 3. | Complete Field-to-Finish System for All Types of Surveys - Gerald Mckelvey, Wild Heerbrugg Instruments, Inc. |
| 8:45 am | 4. | Zeiss Field-to-Finish System - V. Litpmann, Carl Zeiss, Inc. |
| 9:05 am | 5. | New Techniques for Producing the Mississippi River Hydrographic Survey Book - Erwin Balumeyer, Kenneth Balk and Associates |
| 9:25 am | 6. | General Disscussions - Chairman and Panel Members |
| 9:30 am | | BREAK |

TECHNICAL SESSION 9
(Airborne Lasers)

| | | |
|---|---|---|
| 10:00 am | 1. | Session Overview - Jack Stoll, WES, Chairman |
| 10:05 am | 2. | Laser Profiling and Mapping Systems - Joseph Jepsky, Associated Controls and Communications, Inc. |
| 10:20 am | 3. | Airborne Laser Terrain Profiling System Development - Warr[illegible] Latvala, Itech, LTD. |
| 10:35 am | 4. | Application of Airborne Lasers to Corps Proj[illegible]s - Jack Stoll, WES |
| 10:50 am | 5. | Flight Testing the Aerial Profiling of Terrain System - Bill Chapmen, USGS |
| 11:05 am | 6. | General Discussion - Chairman and Panel Members |
| 11:30 am | | LUNCH |

TECHNICAL SESSION 10
(Global Positioning System)

| | | |
|---|---|---|
| 1:30 pm | 1. | Session Overview - Ken Robertson, ETL, Chairman |
| 1:35 pm | 2. | Potential of the NAVSTAR Global Positioning System for the Corps of Engineers - Ken Robertson, ETL |
| 1:45 pm | 3. | Status & Overview of MACROMETER GPS Reveivers - Jim Cain, Aero Service |
| 2:00 pm | 4. | Vertical Reliability of the Global Positioning System - Stephen R. Deloach, Norfolk District |
| 2:15 pm | 5. | Specifications for GPS Surveys - James Collins, GEO/HYDRO, Inc. |
| 2:30 pm | 6. | General Discussions - Chairman and Panel Members |
| 3:00pm | | BREAK |

TECHNICAL SESSION 11
(Photogrammetry and Digital Cartography)

| | | |
|---|---|---|
| 3:30 pm | 1. | Session Overview - Jack Erlandson, Seattle District, Chairman |
| 3:35 pm | 2. | Photogrammetric Mapping and Monitoring of the Manasquan Inlet and Dolosse - David Nale, ADR Associates, Inc. |
| 3:50 pm | 3. | Acquiring an APPS-IV System and Setting Up an all Digital Survey System - Marvin Taylor, Omaha Dist. |
| 4:05 pm | 4. | Coordination of Federal Digital Cartographic Activities - Larry Amos, USGS |
| 4:20 pm | 5. | NOS Digital Charting Standards - NOS, NOAA |
| 4:35 pm | 6. | Annual Mapping Requirements - Larry Amos, USGS |
| 4:45 pm | 7. | General Discussions - Chairman and Panel Members |
| 5:00 pm | | END OF SESSION |

# SESSION I: HYDROGRAPHIC EQUIPMENT DEVELOPMENTS

# NEW DIGITAL SIGNAL PROCESSING TECHNIQUES AS AN AID TO HYDROGRAPHIC AND DREDGING SURVEYS

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## BIOGRAPHICAL SKETCHES

David D. Caulfield is President of Caulfield Engineering and acting as Director of Research for Island Research and Development Corporation. He recieved his Mech. Eng. degree and M.Sc. in physics from Steven's Institute of Technology. He spent many years at Woods Hole, and his primary interests are in the application of signal processing to the problems of oceanography. He is a member of Sigma Xi, and a professional engineer in alberta.

Daniel J. Kenway is Vice-President of Caulfield Engineering and is temporarily seconded to Island Research and Development Corporation as Research Engineer Manager. He received his B.Sc. and M.Sc. in physics from the University of Alberta. His principal interests are in the use of computers to solve real time problems in geophysics. He is a member of the M.A.A., and a professional Engineer in Alberta.

Will Bauer is the subbottom project engineer at Caulfield Engineering. He received his B.Sc. in electrical engineering from the University of Alberta. His principal

professional interests are mathematical modeling and microcomputer hardware/software systems design. He is an E.I.T. and is a member of the L-5 society.

Carl Flatman is the stereo sidescan project engineer at Caulfield Engineering. He received his B.Sc. in electrical engineering from the University of Alberta. His principal professional interests are digital signal processing, remote sensing, and microcomputer hardware and software. He is an E.I.T. and is a member of the I.E.E.E.

## ABSTRACT

During the last decade, the microcomputer industry has had a large impact on the data handling and acquistion portion of hydrographic and dredging surveys. Developments in high speed analog-to-digital converters and microprocessors have opened up the application of signal processing concepts to hydrographic and shallow subbottom data acquistion and interpretation. Two examples are discussed. These are: 1) The Digital Stereo Side Scan System, which allows for the conversion of side scan data records (stereo data on tape) into high resolution bathymetric charts and 2) The Acoustic Core Subbottom System, which allows the conversion of high quality (good signal-to-noise) subbottom data (3.5 KHz, boomer, and sparker) into regional core logs when calibrated for local soil conditions. Each item is briefly described along with its use for engineering applications.

The subbottom analysis Acoustic Core System is reviewed in detail to illustrate the practical problems of applying modern signal processing techniques.

## INTRODUCTION

Practical hydrography is largely based on mature technology. The key components: crystal transducers, wet and dry paper records, TVG amps , etc. have been around and functioning for many decades. Because of the success of these standard components in conventional bathymetry and the impossibility (until recently) of using these or any other components to perform more advanced processing, there has been little impetus to change these fundamentals.

With the advent of microprocessors, a number of changes did occur. Small portable field instruments could be constructed containing microprocessors and for the first time many non-linear corrections became possible in real time.

In order that digital processing be applied to the data, the data must first be sampled and digitized. This involves chopping up the waveform into small pieces and converting each of the sampled levels into a number. Figure 1 schematically illustrates this process. It should be noted that sampling the waveform introduces a considerable simplification. In order to preserve the information content of a signal, approximately 3 samples are required for every cycle of the highest frequency contained in the waveform. Hence, digitized data is always filtered prior to sampling.

This requirement also means that to sample a 10 KHz signal, a 30 KHz sampling rate is required.

Again, due to relatively recent advances in technology, inexpensive analog-to-digital (A/D) convertors are now available with conversion rates of 30 KHz or greater, and resolutions of about 1 part in 2000. These devices are subsystems which convert a voltage level into a number which a computer can then store in its memory and manipulate in various ways.

Acquiring data at rates of 30,000 sample per second or greater, imposes further problems in that large amounts of computer memory and secondary storage are required to preserve the incoming mass of data. Finally, if processing is to be done in real time, then the microcomputer must have sufficient processing power to output the processed data at least as fast as it comes in.

A block diagram of a data acquisition system is shown in Figure 2. It includes the standard elements already discussed, a transducer, amplifiers, an anti-aliasing filter, an analog/digital convertor, and a microprocessor with memory and output devices.

The entire object of this exercise is to perform better signal processing. Recently, instruments have appeared which allow for microcomputer based compensation of heave, and in the case of sidescan - slant range. Spark paper, and wet paper recorders now use micoprocessors for more precise plotting of signal levels. These sorts of applications only scratch the surface. Data may be conditioned with digital filters, transformed into the frequency domain with Fourier transforms, correlated, stacked, and in general enhanced to extract the maximum intelligence available from the signal present.

For the past five years Caulfield Engineering has been principally occupied with the application of various digital signal processing techniques to problems of hydrographic and dredging surveys. Two specific examples of areas where digital signal processing has been successfully applied are:

1. Digital Stereo Sidescan Sonar

2. Enhanced Subbottom Analysis (Acoustic Coring)

In both of these areas, field programs have already been conducted and the data acquired has been analyzed using signal processing techniques. To further this work, Caulfield Engineering is currently developing new research systems in both these areas for Island Research and Development Corporation of Victoria, Canada.

## STEREO SIDESCAN SONAR

In 1983, the construction of Esso Resources Canada Ltd.'s Caisson Retained Drilling Island project in the Beaufort Sea was in the prototype testing stage. After the caisson had

been positioned, accurate measurements of berm backfill were required both to control dredge dumping performance and to monitor ice and wave scour of the erosion protection pads (see Figure 3) during the lifetime of the artificial island.

Due to the inability of vessels to come close enough to the steel caisson island to perform conventional bathymetry surveys, a special system was required. This system which was contructed and used during the summer of 1983, and was based on the concept of digital stereo sidescan sonar and supported by Esso Resources Canada Ltd.

Narrow beam scanning sonars have been previously used for bottom bathymetry (for example see Albers 1965). Such systems required either large arrays, or narrow beam high frequency transducers, which were mechanically oriented.

Using a digital system based on Caulfield Engineering's CE-7000 microcomputer it was possible to implement a sonar which co-ordinated the returns received at two separate sidescan transducers. Using a simple geometric analysis (see Caulfield. Kenway, and Gold, 1983) it was then possible to triangulate the narrow beam returns and compute the depth and range of the target reflectors. Figure 4 shows the nature of the geometric analysis. Knowing the depth (c) of the upper transducer, the tranducer separations (d and e) and the upper and lower path length (f and g) the depth and range may be calculated by solving:

$$g^2 = a^2 + b^2 \quad \text{------(1)}$$

and

$$b = Ab^2 + Bb + C \quad \text{---------(2)}$$

where

$$A = 4(d^2 + e^2) \quad \text{-------- (3)}$$

$$B = 4(f^2 - g^2 - d^2 - e^2)e \quad \text{---- (4)}$$

$$C = (f^2 - g^2 - d^2 - e^2)^2 - 4g^2d^2 \quad \text{---- (5)}$$

The practical implementation of the system involved the use of a telescoping boom mounted on the side of the survey vessel. (see Figure 5) Attached to the end of this boom was a submerged positive buoyancy portion containing the sidescan transducers.

Surveys were conducted by circumnavigating the caisson repeatedly to obtain data from the sidescan sonars, and conventional systems mounted in the system fish. Figure 6 gives a typical navigation plot complete with fix marks. Figure 7 shows a plot of the bottom returns from each of the two stereo sidescan channels. It was possible through the use of signal processing techniques to correlate the various returns contained within the signal. This was done using a signal processing system similar to the one described in Figure 2. On the basis of these correlations, approximately 200 near-caisson bathymetry measurements were achieved in one survey. Coupling this data with that obtained by conventional echo sounding, a complete data set describing

the bottom in the vicinity of the caisson was compiled. This data was highly anisotropic in its distribution since the data points acquired were either along, or parallel to the survey vessel path. In order to accurately contour this data, software developed by Gold (1983) was employed to generate the map shown in Figure 8.

As a survey method, stereo sidescan technology has the unique advantage of being able to do depth surveys over a wide swath of area on each survey line being run. The method allows one to make depth measurements at several intermediate points away from the side of the boat where conventional echo sounders can only obtain one measurement. This can greatly reduce the number of survey lines which need be run and hence the cost and duration of the survey. There are several complications which must be taken into account when developing a practical version of stereo sidescan. Among these are the extreme sensitivity of the process to yaw and roll of the system fish and the sensitivity to the geometry of the area being surveyed. The resolution of the system is fairly good. Although Stereo sidescan is still a new technology, resolutions of 1 meter at ranges of 50 meters are achievable.

## ENHANCED SUBBOTTOM ANALYSIS

There are several standard tools for acquiring subbottom (or shallow seismic) data. Conventionally the data from a boomer, sparker, or tuned source is presented on paper records and analyzed to find major horizons. If possible, seismic horizons may be "truthed" against actual core data taken at strategic sites.

Based on the work of Hamilton et al., various material types have been catagorized according to their acoustic and physical properties. Figure 9 presents a graph of impedance versus density for surficial sediments measured by Hamilton. What is striking about this plot is the close approximation to a linear relationship. Figure 10 is a tabulation of material type versus acoustic impedance based on the work of Hamilton and Bachman (1982). On the basis of this tabulation it should be possible via an acoustic measurement of impedance to determine the material type of the sediment responsible.

Ideally shallow seismic reflection can be calculated on the basis of acoustic impedance mismatch according to the Rayleigh Reflection formula

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \qquad \text{--------(6)}$$

Accordingly, if the total incident energy known and the reflection coefficient R is calculated on the basis of

$$R = \sqrt{\frac{E_{layer}}{E_{incident}}} \qquad \text{- - - - - - -(7)}$$

where $E_{layer}$ is the energy reflected from a given layer and $E_{incident}$ is the energy incident.

Then the impedance of the first layer (sea floor-water interface) may be calculated using the formula

$$Z_{layer} = Z_{water}\left(\frac{1 + R}{1 - R}\right) \qquad \text{- - - - - -(8)}$$

In a like manner, if the energy reflected by the first layer is removed from the incident energy, then the energy remaining is the energy incident on the second layer. Formulas (7) and (8) can be iterated over and over again to produce the impedance of each subsequent layer with the subtraction of the energy reflected above.

Unfortunately this simple concept is made more complicated by necessity to allow for attenuation losses. In the first approximation these are given by

$$e^{-\alpha x} \qquad \text{- - - - - - -(9)}$$

where $\alpha$ is a function of the incident frequency, and density of material.

Figure 11 shows the flow of information in the subbottom analysis system. In the higher precision versions of the program, an additional step - involving a Fourier transform is involved prior to the energy loss correction. The reason for this extra step is to make a more precise attenuation correction for each of the spectral bands within the signal window.

In practice data is acquired using a system similar to that shown in Figure 2. Once analyzed the output may be presented in a number of forms.

Figure 12 shows a comparison between an actual core and an "Acoustic Core". A more detailed comparison based on 274 samples is shown in Figure 13. A strong central peak is evident. Synthetic seismograms, based on ideal layered models have been computed and subsequently analyzed, also yielding reasonable correspondences.

Further extending this notion, predictions of grain size and porosity may be made on the basis of Hamilton's regressions. Figure 14 shows some observed results.

The computation time required for the calculation of one subbottom analysis is approximately one quarter of a second with current equipment, so that impedance cross-sections can

be calculated and displayed on a colour printer in real time (or almost real time).

Figure 15 shows a black and white reproduction of a color impedance cross-section computed from harbour survey data taken with a boomer. This sort of presentation can be produced in the field in real time with tremendous advantages. It should be noted that many deficiencies remain with the current subbottom analysis system:

1. No source deconvolution is applied, hence resolution is limited to 2 or 3 times, the source pulse length.

2. No removal of multiples due to reflections at the water surface is performed, hence shallow water limits the depth of analysis.

3. Limited corrections are made for surface roughness, or other effects identifiable by stongly anomalous frequency effects.

4. Since the technique is based on reflection, truly anomalous reflectors such as trapped gasses, or organics will be consistently misinterpreted.

5. Although the system produces a reflection derived acoustic impedance, calibration of those acoustic impedances with local cores is required for a reliable correlation of horizons.

Some of these problems will be addressed by research programs jointly planned by IRDC and Caulfield Engineering. However the system as it stands is capable of providing reliable enhanced reflection information far beyond that available from spark paper recorders and is already available as a prototype field-worthy system. Despite the items mentioned above, the effectiveness and utility of the present field-worthy system is such that it provides a valuable tool for the analysis of layering phenomena. Figure 16 shows the results from the analysis of a synthetic three layer seismogram. Results utilizing both the reflectivity based (colour system) and Fourier based methods are shown.

## CONCLUSION

This paper has discussed only a few of the novel solutions possible through the application of digital signal processing to problems related to hydrographic survey and subbottom measurements. Even from this limited perspective it is obvious that with the increased availability of signal processing in the field many new types of measurements will be possible.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Esso Resources Canada Limited, Gulf Resources Canada

Incorporated, and Swan Wooster Engineering Limited. Many of the Figures used in this paper are reprinted from earlier work done for these companies (see reference papers 6 and 7. We also acknowledge our unending debt to the work of E.C. Hamilton on sediments and their properties.

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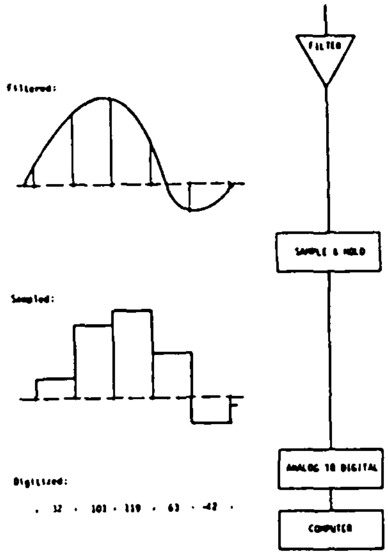


Figure 1. Sampling and Digitizing

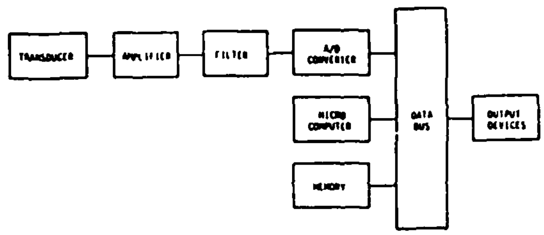


Figure 2. Fundamental Signal Processing System

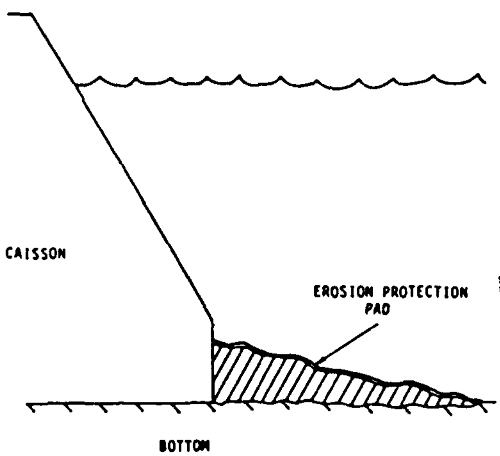


Figure 3.

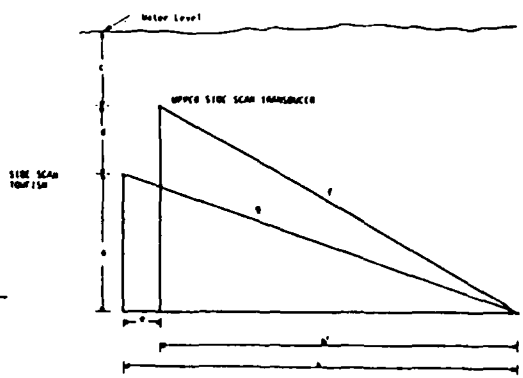


Figure 4.

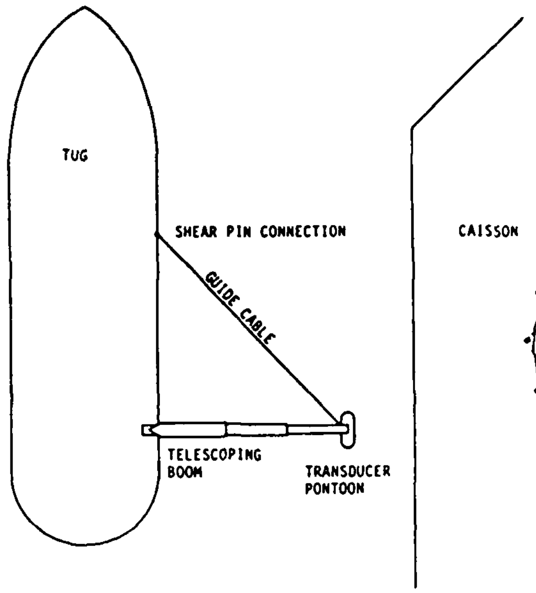


Figure 5.

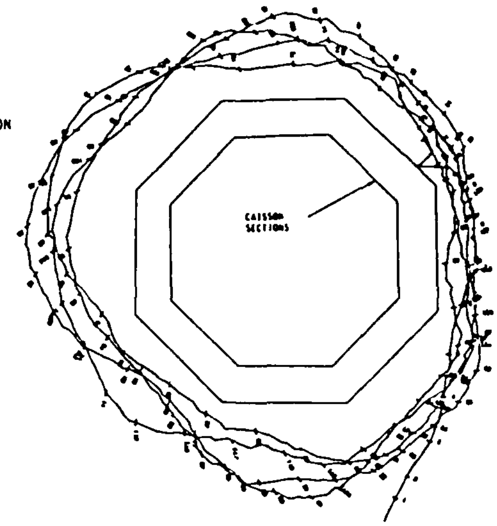

Figure 6. Typical Navigation Plot.

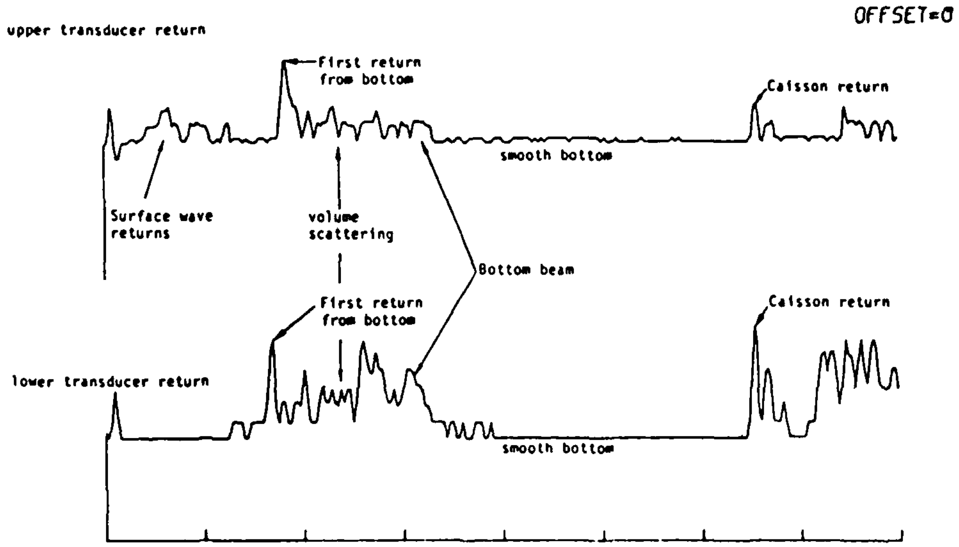


Figure 7.

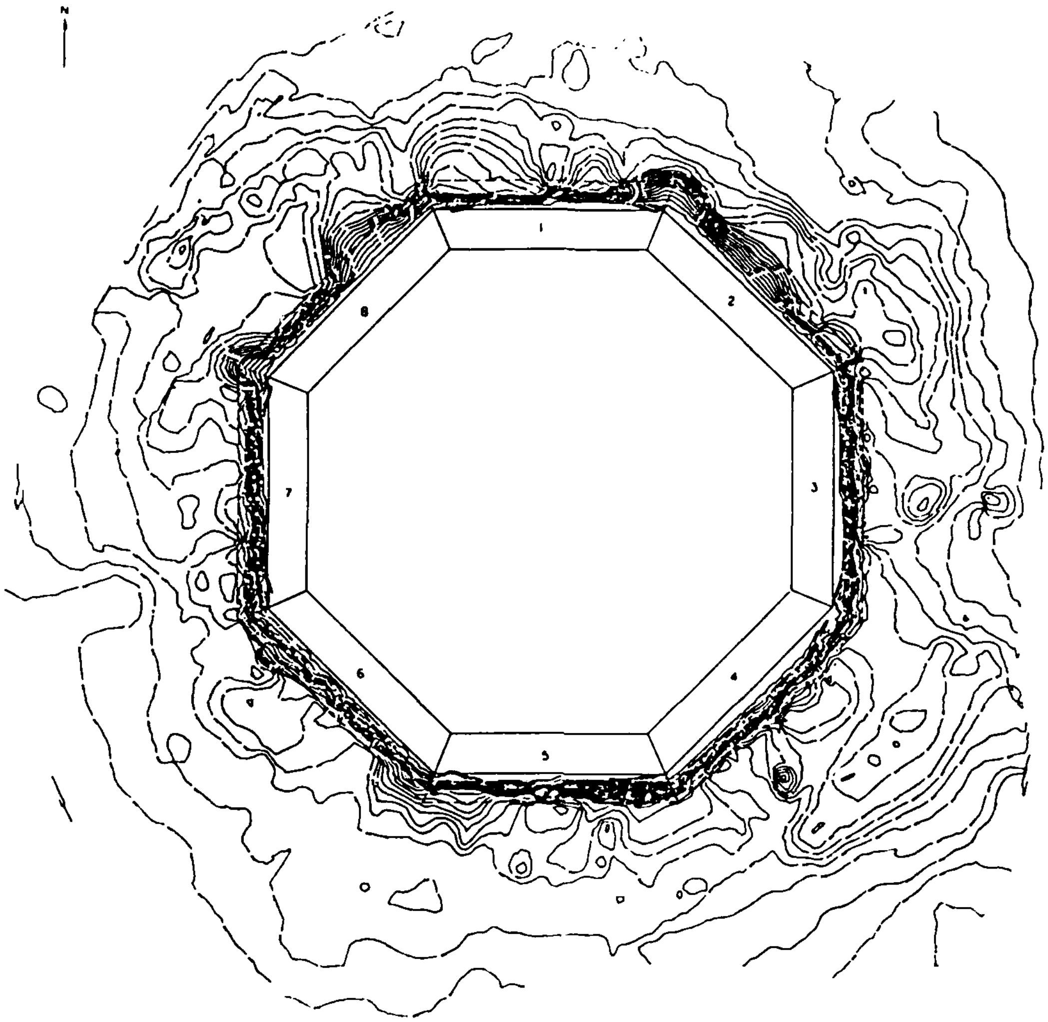


Figure 8.

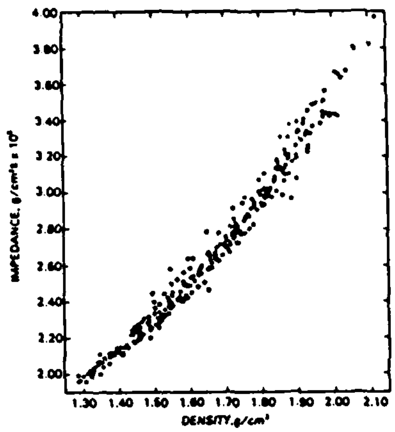


Fig. 9 - Saturated Bulk Density Versus Impedance, Continental Terrace (Shelf and Slope). (Hamilton and Bachman)

| DESCRIPTION | ACOUSTIC IMPEDANCE $\frac{\times 10^2\ g}{cm^2\ sec}$ |
|---|---|
| Water | 1450 |
| Silty Clay | 2016-2460 |
| Clayey Silt | 2460-2864 |
| Silty Sand | 2864-3052 |
| Very Fine Sand | 3052-3219 |
| Fine Sand | 3219-3281 |
| Medium Sand | 3281-3492 |
| Coarse Sand | 3492-3647 |
| Gravelly Sand | 3647-3880 |
| Sandy Gravel | 3880-3927 |

(After Hamilton and Bachman)

(Corrected for Temperature and Salinity)

Figure 10. Soil Classification Versus Acoustic Impedance Range.

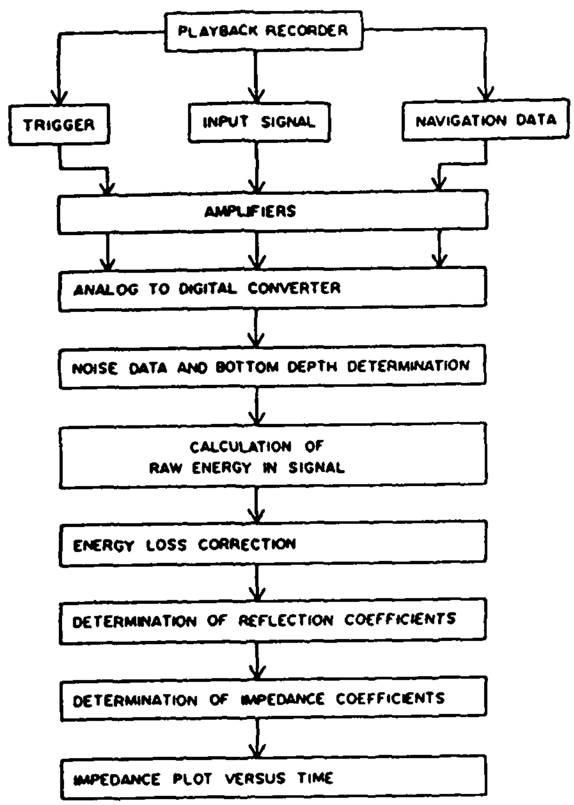


Figure 11.

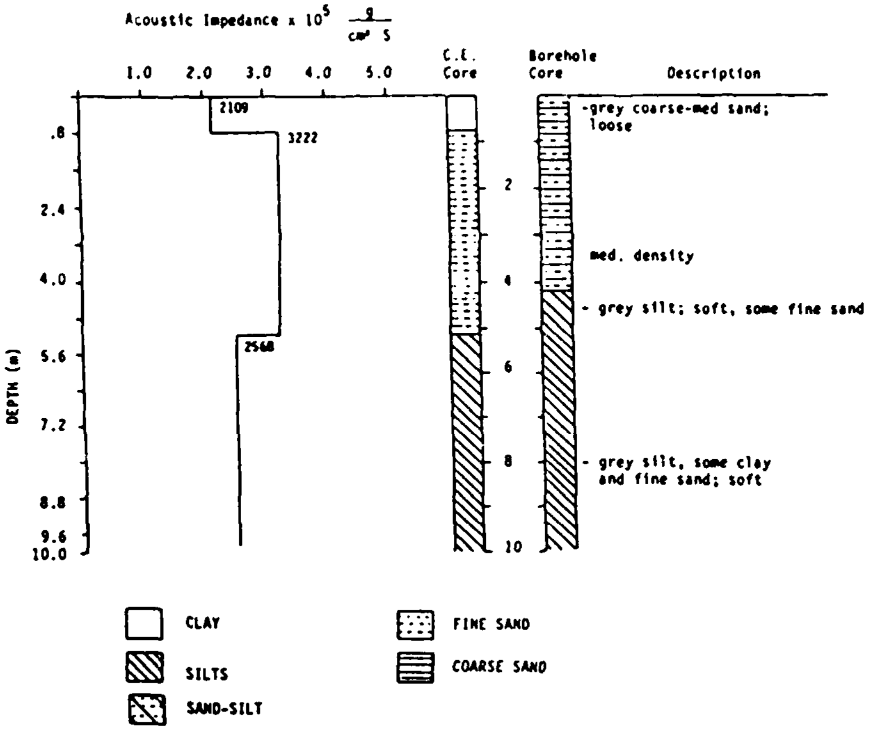


Figure 12. Comparison of Acoustic and Borehole Cores from Caulfield et al.[10]

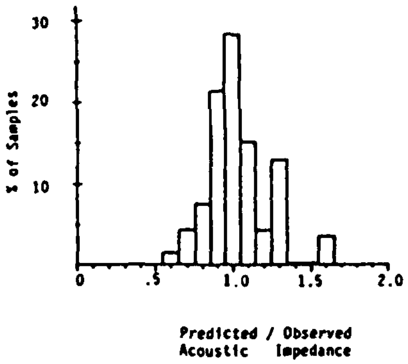


Figure 13. Statistical Comparison of Acoustic Impedances.

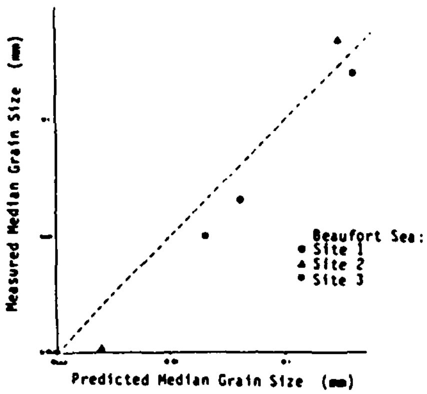


Figure 14. Predicted Versus Measured Median Grain Size (mm).

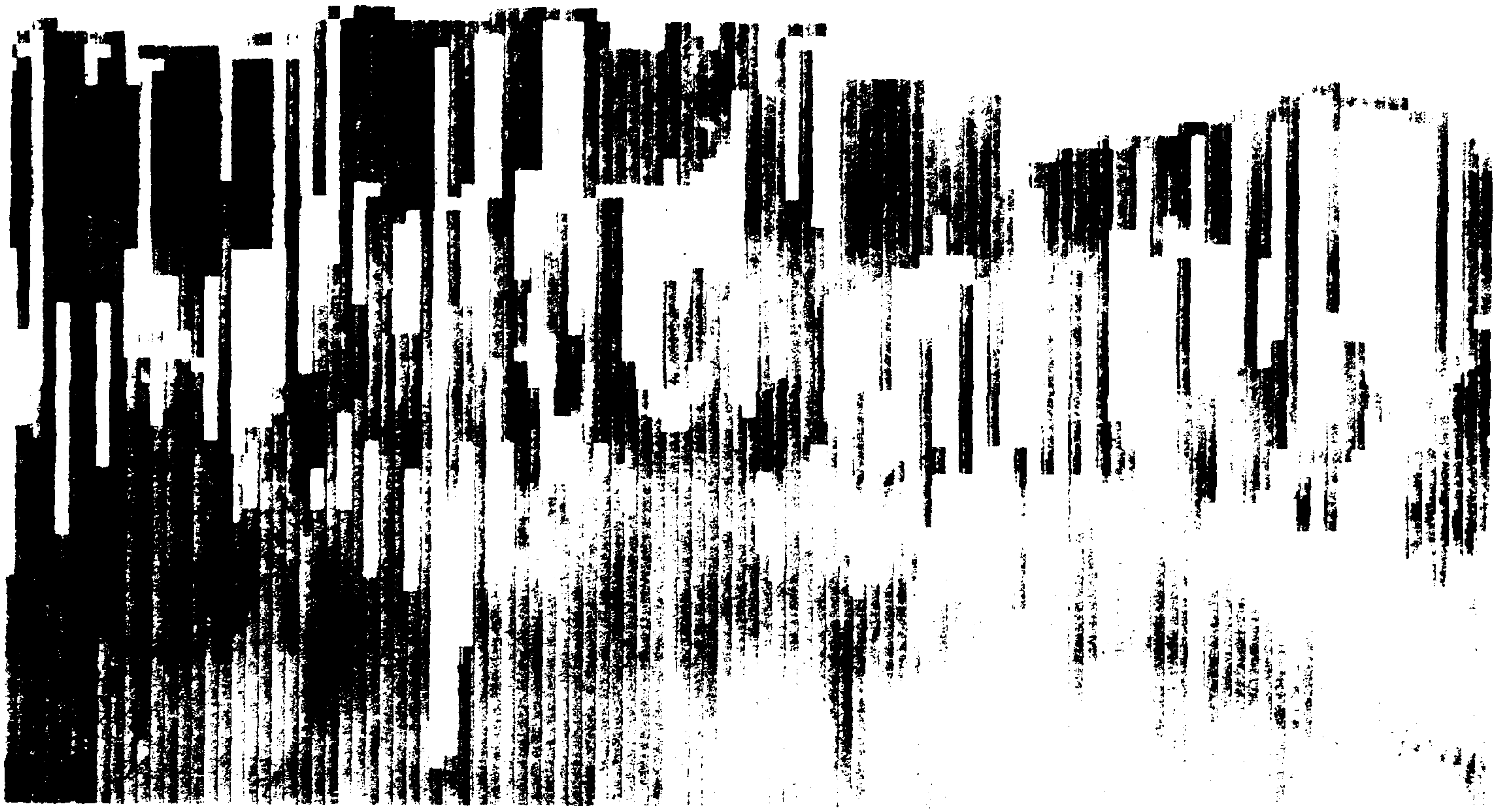

Figure 15. Subbottom Data Processed for Acoustic Impedance. (Original in Color)

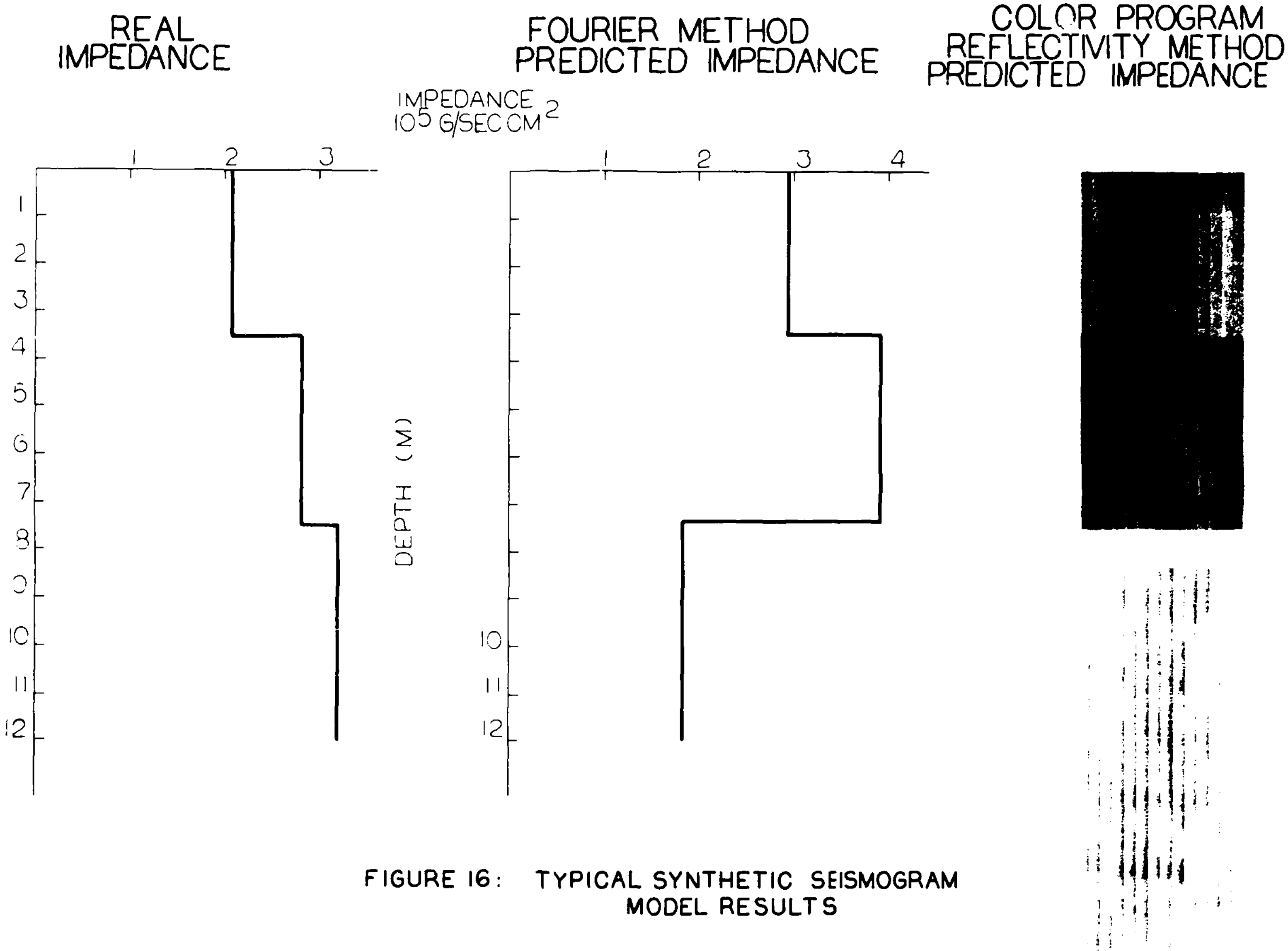


FIGURE 16: TYPICAL SYNTHETIC SEISMOGRAM MODEL RESULTS

# THE NEXT GENERATION SURVEY ECHO SOUNDER.

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## BIOGRAPHICAL SKETCH

After completing 5 years of education at DECCA-ARKAS as an electronic engineer, Erik Brinch Nielsen entered the Copenhagen Engineering College, Department of Electrical Engineering. After his graduation in 1968, he was employed by the Danish Navy several years in the Electronic Division, connected to the Hydrographic Office. He founded the company NAVITRONIC in 1973, designing and manufacturing Hydrographic Equipment.

## ABSTRACT

NAVITRONIC has approximately 400 installations in operation, mainly related to hydrographic surveying. This covers a range from small portable survey systems, to large integrated systems for geophysical surveys and research vessels. NAVITRONIC has many different users all over the world, including hydrographic offices, harbour authorities, dredging companies, survey companies, and oil companies. With this background and experience in designing electronic and mechanical equipment for hydrographic purposes, we have, during the past three years, developed the third generation of Hydrographic Echo Sounders, endeavouring to meet as many requirements as possible for the entire survey field.

## INTRODUCTION

In 1970, NAVITRONIC designed the first digital Echo Sounder for survey applications available in the world, the SOUNDIG-10. Until then, the only alternative had been digitizers connected to conventional echo sounders.

It took many years for the Digital Echo Sounder to be accepted, and still, many surveyors do not accept the type of records which come from the digital echo sounder's stripchart recorder. The simplest recorder, available at this time, was a modified thermo printer. This recorder should give the surveyor more information about the bottom, compared with the stripchart recorder. Furthermore, there were very few mechanical parts in the thermo recorder and the unit was relatively inexpensive. A number of drawbacks, such as increased resolution, no colour shading (just black and white information), combined with the fact that thermo-paper is difficult to store for extended periods, has led us back to the graphic line scan recorder solution. This still seems to be the most economical solution, if the requirements call for a storable high resolution paper recorder.

NAVITRONIC, in developing the SOUNDIG-30, has made great improvements to the old type of recorders and also has built-in many new features, required in future survey operations.

The new Echo Sounder, SOUNDIG-30, is still separated from the recorder, as is the case in the old model, and this will keep the door open for possible later use in other better recording techniques. The new Echo Sounder is a further development of the NAVITRONIC second generation Multi-channel Echo Sounder MCS-1B. This Echo Sounder was the first professional micro-processor controlled sounder on the world market. Sixty-eight units are now in operation, almost all in swath survey applications for which they were designed. All the best ideas from the SOUNDIG-10, and from the Multi-channel Echo Sounder MCS-1, have been combined with new technology in the forthcoming SOUNDIG-30.

As the requirements to accuracy are more exacting, this has led us into designing an accurate calibrating instrumentation for the Survey Echo Sounders.

The Echo Sounder Calibrator and Simulator ECS-1, designed in 1984, is able to control accuracy, sensitivity, power output, TVC, APC, and AGC settings, bandwidth, digital bottom tracking and more. The first instrument in the world of its kind.

The ECS-1, combined with the new Sound Velocity Probe, also introduced in 1984, enables the old and not too accurate method of echo sounder barcheck. This new Sound Velocity Probe, SVM-1, and the Deck Unit Monitor SVM-1, can be used while the ship is underway. Several measurements can now be taken without interfering with the survey operation.

These new methods and instruments make it possible to measure depths with the highest possible accuracy, only limited by the physical laws.

SOUNDIG-30

The NAVITRONIC Hydrographic Echo Sounder SOUNDIG-30 is the first combined hydrographic, geophysical and oceanographic echo sounder on the world market. The instrument is designed for shallow water, deep sea, high speed and penetration operations, all in one unit.

With close to 15 years of experience in modern sounding methods, NAVITRONIC has designed the first multi-purpose Echo Sounding system for survey use. The SOUNDIG-30 is designed to work under the most difficult operating conditions, where reliable data for computer systems is mandatory.

# SMALL BOAT SURVEY SYSTEM

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## BIOGRAPHICAL SKETCH

Barry McCleave is an electronics engineer in the Instrumentation Services Division, Waterways Experiment Station. He received a BS degree in electrical engineering from Mississippi State University in 1970. Following graduation he spent four years in the US Army. During the last three years of his Army tour of duty, he was assigned to the Waterways Experiment Station as one of the military engineers on the staff. He received an honorable discharge from the military in 1974 and continued working at the Waterways Experiment Station as a civilian engineer. In 1980 he was sent back to Mississippi State University for graduate studies under a Government-sponsored long term training program. He received an MS in electrical engineering in 1981. His current work at the Waterways Experiment Station is primarily with computer based data acquisition and control systems. He is a member of IEEE and a registered professional engineer in the state of Mississippi.

## ABSTRACT

The need for an automated hydrographic survey system suitable for small boats has been a general Corps requirement for more than a decade. Numerous small boat systems have been designed and evaluated, with varying degrees of success. A rapidly advancing state-of-the-art in electronic equipment has created a situation where the design possibilities and the user perception of requirements are changing continuously. During the past year, the Waterways Experiment Station has been working on a small boat survey system based on state-of-the-art components available in 1984. A small briefcase size computer has been selected for the system, which has computing power sufficient for either small or large survey boats. A depth measuring instrument which splits the functions of signal detection and display into two packages permits system configurations not possible with conventional depth recorders. Software being written for the system will incorporate all of the Corps surveyor requests that are possible. Field trials of the system are planned for the summer of 1985.

# FIELD EXPERIENCES WITH KRUPP ATLAS HECO 10 HEAVE COMPENSATOR

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## BIOGRAPHICAL SKETCH

Juris Jurisons, born in Riga, Latvia, is a Supervisory Survey Technician and presently Chief of Hydrographic Surveys in Portland District. After arriving in the United States in 1950, he attended Benson Polytechnic High School and Portland State University. He has been with the Corps of Engineers since 1959, and has been involved in hydrographic surveys in the South China Sea (Republic of Vietnam), Saudi Arabia and the Republic of Nicaragua (Porto Corinto). Juris is a member of ASCET and SAME.

## ABSTRACT

The US Army Corps of Engineers, Portland District, is charged with maintaining numerous miles of inland waterways with 12 ocean entrances. Two of these entrances are large rivers entering the Pacific Ocean and support deep draft ocean traffic. It is a well known fact to hydrographers that an accurate depth determination on these ocean entrance bars is difficult and has been a concern to surveyors and dredge operators alike. Before acquiring the *HECO 10 Heave Compensator*, we were faced, as are hydrographic surveyors everywhere, with estimating the swells during survey operations and then "trimming" the analogue trace by "eyeball method." By installing this electronic device in our 65 ft. survey-boat HICKSON, we haven't only increased our survey accuracy and repeatability, but also the number of data gathering days.

## INTRODUCTION

After looking at and evaluating several heave compensating methods, the Portland District decided to purchase and install the HECO 10 from KRUPP ATLAS in 1983. Several factors thought favorable in the purchase were:

1) Portland District already owned and was using KRUPP ATLAS DESO 10 survey sounder.
2) This was one of the few on-line compensating systems.
3) We were highly pleased with their manufactured equipment that we already owned (DESO 10).

## GENERAL

As described in their own sales brochure, ATLAS HECO 10 is a gyro-stabilized heave compensator for on-line compensation of ATLAS DESO 10 and 20 depth measuring errors caused by heave and swell at sea. The vertical motion of the surveyboat is determined and compensated by applying an inertial method. An accelerometer with its sensitive axis vertically stabilized by a horizontal gyro measures the vertical accelerations resulting from heave. The acceleration signal is fed into an analogue amplifier which, in the range of heave periods from 1 to 20 seconds, shows the behavior of a double integrator. The heave signal then is generated by double integration of the heave acceleration. The installation on our vessel is such that only the control panel is visible and the other components of the system are not. For individual components of the HECO 10 see figure 1.

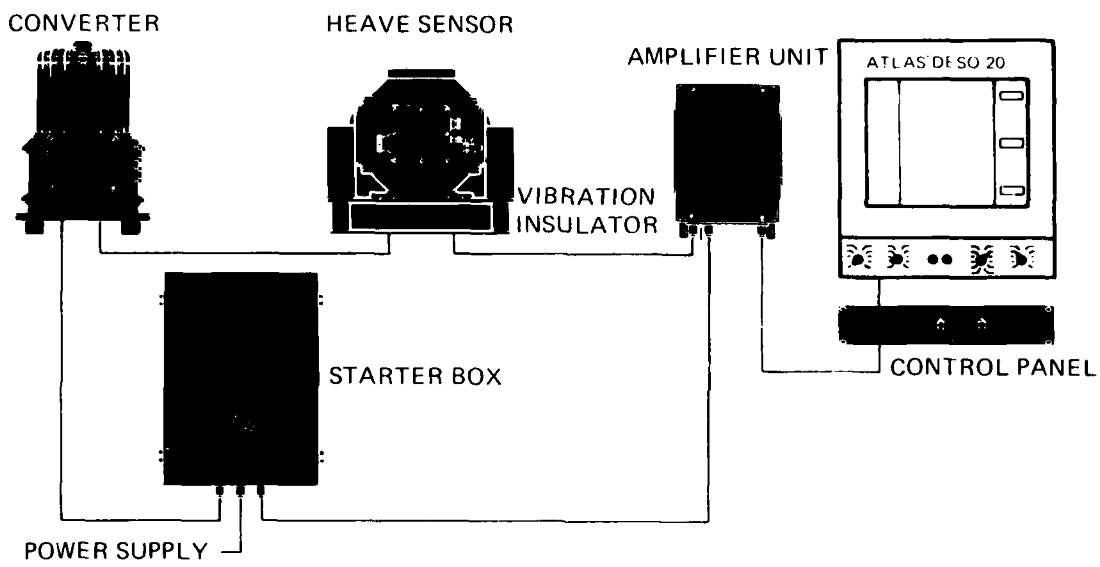


FIG. I

## FIELD EXPERIENCE

After installing the system in the summer of 1984, we awaited the rough weather of our winter season for putting the HECO 10 through its paces. The main area for testing was the Columbia River Bar, chosen for the fact that the bottom contour is fairly smooth due to yearly dredging in

a hard pact sand. By running a pre-determined course, under different sea conditions, with the HECO 10 both on and off, we came to the conclusion that this system seems to approximate the true depths better than what we have had to use previously. The normal procedure of "trimming" the analogue trace by the "eyeball method" involves factors that a good electronic compensator seems to minimize. The size of swells has to be estimated during survey operation. If digitizing and smoothing is done in an office by someone without detailed knowledge of survey area, the natural bottom configuration may be easily misinterpreted. The person must make the determination of which part of the analogue trace comes from the action of the vessel (swell) and which from the natural bottom--such as a rock pinnacle or a reef. Even under the best of circumstances, the repeatability of trimming swells by human eye is not as good as doing it by electronic means. As can be seen of analogue trace from one of these runs, (figure 2), several important determinations can be ascertained visually during the time of survey:

1) Is the HECO 10 working properly?--observe the transducer line varying with the swell (a in figure 2).
2) Is the depth sounder producing bottom trace as it normally would without the compensator? (raw bottom trace b in figure 2).
3) Is the bottom contour being compensated by HECO 10? (c in figure 2).

It may appear from the compensated analogue trace (c) that further minor corrections, specifically in-between swell troughs, could be achieved. This is accomplished by our "smoothing" routine which means the digitized signals through the onboard micro processor, and with the proper positioning input, you now have a reasonable survey.

As with all electronic systems, there are some pluses and minuses. The components are large enough to where they would be hard to install into smaller vessel than our 65 ft. survey-boat. As in all gyro-based systems, care has to be taken not to move the vessel without the electrical power on. Time lag after taking 90 and 180 degree turns could be improved. As for pluses--seems to have a high reliability and in our case a terrific KRUPP ATLAS staff in their regional office in Seattle.

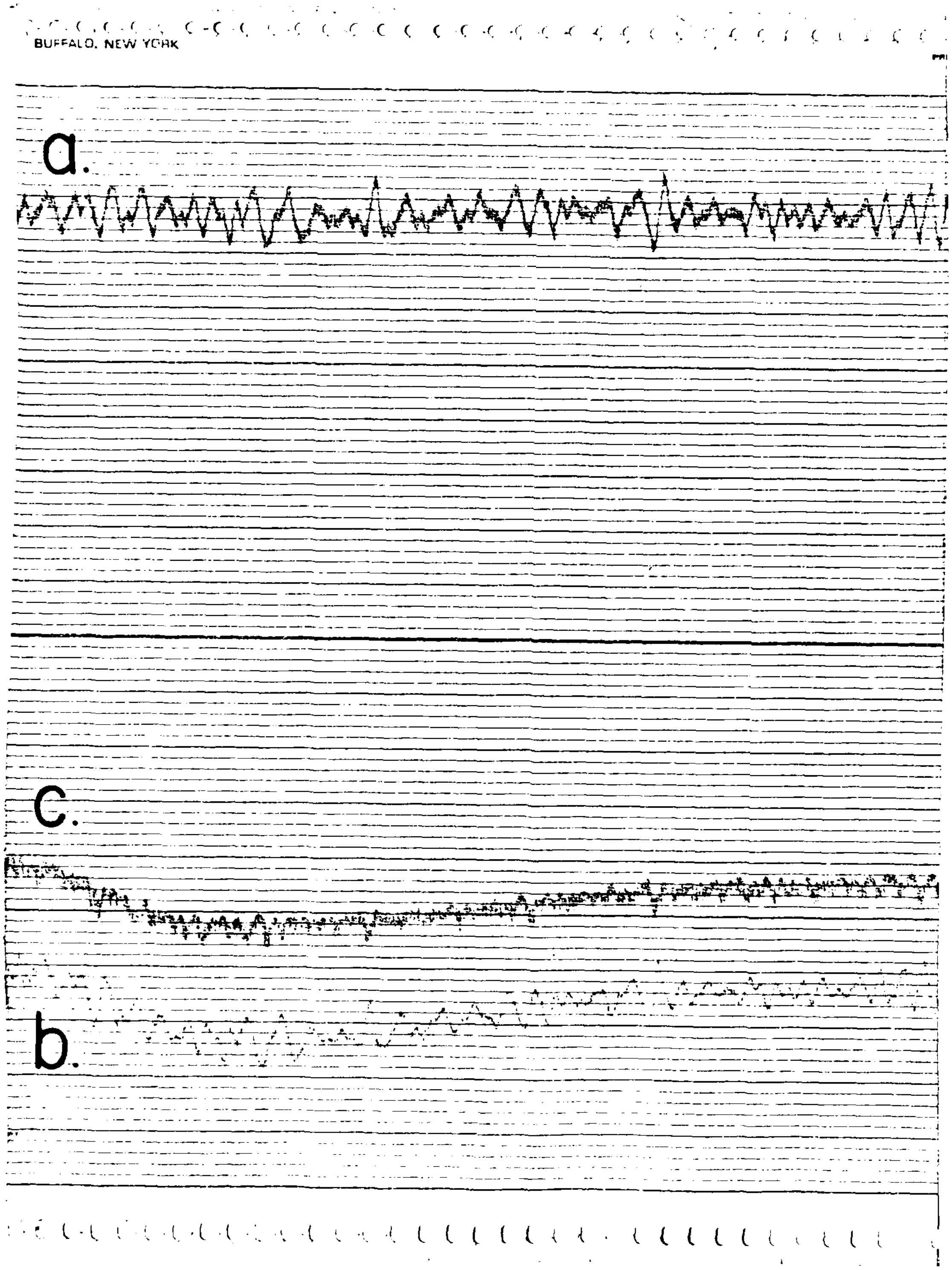


FIG. 2

## SESSION II: HYDROGRAPHIC SWEEP SYSTEMS AND VESSEL DESIGN

# DETROIT DISTRICT MULTI-TRANSDUCER SURVEY SWEEP SYSTEM

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## BIOGRAPHICAL SKETCHES

Brian F. Apsey is Marketing Director of the Hydrographic Systems Division of Odom Offshore Surveys, Inc. He has been involved for the past twenty-five years in the hydrographic survey industry worldwide, working with Government and private industry in various countries on field engineering, product support and sales of hydrographic equipment. He is a member of The Hydrographic Society.

Gerard Zieleman is Executive Vice-President of Marketing for Comstar, Inc. In 1960, he joined I.N.A., the Decca Survey, Ltd. representative in the Netherlands. He was technically responsible for the first HI-FIX tm chain used in the construction of the new harbor entrance to Amsterdam. His work has been related to hydrographic survey and dredge positioning systems and since 1975 with automation in this field. On behalf of Decca Survey, London he was involved in automated positioning projects worldwide. He is a member of The Hydrographic Society, Dutch Branch.

## ABSTRACT

The Detroit district Multi-Transducer Survey Sweep System, ECHOSCAN tm consists of a barge mounted, 32 transducer, acoustic sounder, which is interfaced with positioning equipment and with a data acquisition system capable of displaying, printing and plotting both position and depth data aboard the survey vessel. The barge is self-propelled (i.e., twin screw capable of moving in any direction) and weighs approximately 200 tons (outfitting and ballast inclusive).

The microprocessor based acoustic control and formatting equipment was provided by Odom Offshore Surveys, Inc., and the data acquisition display and processing hardware and software were provided by Comstar, Inc.

Two barges are now equipped with ECHOSCAN tm systems to survey the critical channels in the St. Mary's and St. Clair Rivers.

## INTRODUCTION

Since 1972, The Detroit District has attempted to acquire an Automated Multi-Transducer Hydrographic Survey Sweep System. Navigation channels in the District are blasted out of solid rock and surveys are needed to discover bolders that roll into these channels. Previous Sweep Systems were either too expensive and complex to install, or they did not offer the required presentation and processing of data. In 1983, the Detroit District invited bids for two systems that would meet all of their specifications including 100% coverage of a 120 foot swath, track guidance, data presentation and processing.

Odom Offshore Surveys, Inc. of Baton Rouge, Louisiana, working closely with Comstar, Inc. of Houston, Texas, was the successful bidder. This paper describes the two ECHOSCAN$^{tm}$ systems delivered to Detroit in September, 1984.

The navigation channels are 30 miles long and from 400 to 1,000 feet wide. In the St. Mary's River on the United States/Canadian border, the navigation season is so short that it would take two or three years to complete a survey using a mechanical sweep, and a single-transducer survey could never assure picking up all the individual bolders. With the Odom/Comstar ECHOSCAN $^{tm}$, the District should be able to complete the total bottom survey in one season.

Previous acoustic sweep systems have either been simple analog systems with four to six transducers and a recorder, or highly complex and expensive systems with many separate transmitters, receivers, controllers, formatters, and interfaces. Modern microprocessor technology and Odom's experience with ECHOTRAC$^{tm}$ has enabled us to produce a system which is simple, compact and relatively inexpensive.

## SURVEY VESSEL

Several alternatives were considered for deploying a Multi-Transducer Sweep System, including the following:

1. A detachable free-floating boom, towed ahead of the survey vessel.

2. Booms mounted on both sides of the vessel that can be swung out of the way when not surveying.

3. A large, self-propelled barge that can be driven perpendicular to its axis with the transducers installed through its hull or in a support device alongside the vessel.

The third alternative was chosen because it was felt that in the prevailing conditions, the transducers would be less susceptible to damage and the greater mass (200 tons) of the barge would offer the best stability and eliminate the need for heave compensation.

One of the Detroit barges is illustrated in Figure 1. It is 100 feet long with 32 transducers spaced along a catwalk that extends some ten feet beyond each end. These extensions can be raised when docking. The vessel is equipped with two 360 degree propulsion systems so it can be driven along its axis or perpendicular to it while surveying. All of the acoustic control navigation, data logging and processing equipment is installed in the pilot house and the survey room.

## SYSTEM CONFIGURATION

A block diagram of the complete system is shown in Figure 2.

The computer, printer, plotter and data formatter are installed in tne survey room together with the positioning range processor and the acoustic control equipment. The positioning system transponder is mounted on a mast located above the center of the transducer array (between transducer numbers 16 and 17). Track guidance and other data is displayed on the CRT monitor in the pilot house while the heading sensor is mounted on the roof.

## ACOUSTIC CONTROL EQUIPMENT

The acoustic control equipment of ECHOSCAN tm expands on the microprocessor technology developed for Odom's standard dual frequency survey sounder ECHOTRAC tm. It consists of six micro processor-based units, a recorder, four transceiver units (TRU) and a data formatter.

The recorder controls up to four TRU's and produces a chart record of all data channels simultaneously by means of a "fixed head" solid state printer (no stylus). The control and interface functions which are necessary to combine all depth information into one RS232 data stream for external computer processing, are included in the recorder. Velocity of sound correction for bar checks, together with other parameters such as, Draft, Depth Alarm and a choice of displaying either minimum, maximum or the mean depth of the 32 transducers also are controlled by the recorder.

Each TRU is actually an independent microprocessor based, eight-channel sounder and digitizer. The sounding frequency selected by Detroit is 200 KHz, although other frequencies up to 1 MHZ can be supplied. Power output into the 16.5 degree, transducers is adjustable to 50 watts.

## NAVIGATION AND TRACK GUIDANCE

Positioning and navigational guidance are provided by a Del Norte 540 Trisponder tm System interrogating 2, 3, or 4 Remotes with updates every .6 seconds. A Digicourse Heading Sensor facilitates keeping the vessel perpendicular to the required track. This information is displayed on color monitors in both the pilot house and the survey room.

# DATA ACQUISITION AND PROCESSING

All depth data, together with data from the positioning system and the heading sensor, are routed through the data formatter to the computer.

The contract called for total bottom coverage and continuous data collection over a maximum survey track length of ten miles with bottom speed of up to four knots and depths ranging between 18 and 40 feet. These requirements, together with time, position, heading, gauge correction and depth gathered from 32 transducers recorded every six-tenths of a second, dictated the capacity of the system computer.

Two examples will serve to illustrate the tremendous amount of data presented for the computer to process and store.

Example 1:

In each sample, 32 depths, x and y position, heading, speed and gauge readings are stored. At an average speed of 3 feet/sec. (1.7 knots) logging a record every .6 of a second, by the end of a 10 mi. track, 29,000 samples will have been collected. At 96 Bytes/sample approximately 2.8 Mega Bytes of memory storage capacity is required.

Example 2:

If the average speed decreased to 1 ft. per/sec. given the same track length, then in 15 hrs. of data logging, at the 0.6 second sample rate, a total of 88,000 samples will have been stored in a memory space occupying approximately 8.5 Mega Bytes.

The center position of the transducer array is calculated every .6 seconds from either 2, 3, or 4 Trisponder ranges. These ranges are filtered through special software routines to reject erroneous reading and then converted to State Grid Coordinates using a spheroid solution.

Because of its speed, versatility, ease of programming and reliability, the Hewlett-Packard Model 9000 Computer was chosen for the ECHOSCAN^tm application. As delivered, the 9000 is configured with a high resolution color graphic monitor, a 32 Bit CPU, 1.5 Mega Bytes internal memory, RBG Interface for driving an external color monitor, Printer and Plotter interfaces, a 19.2 K Baud Serial Interface, a 520 K 5-1/4" Floppy Disk Drive, and a 10 Mega Byte Winchester Hard Disk. The Operating System, Application Programs, and all data gathered in a 10 mi. track are stored on the hard disk.

Before starting the survey, the operator must define the work area. Using a system of menus and prompts, the operator enters all relevant information such as station coordinates, survey blocks and lines, chart boundaries, and scale. To ease identification later, data such as boat number, surveyor identification, and name of work area are entered in this same file. A menu driven entry mode is provided to insure input data veracity and easy data entry

for the operator. Each menu is divided into groups and subgroups. Each smaller division is presented with its own menu, all linked to the original by headers. These headers identify the larger group and options are provided under them from which to select or identify parameters. If the parameters are common and have been entered earlier, the user simply selects that particular survey parameter file and verifies its accuracy using that network of menus and the system's on-screen editing features.

A special option in the main menu is available to draw on the screen a plan view plot of the defined survey area. A dump of the screen can then be made to either the printer or the plotter. Using the plotter, the grid and channel can also be drawn in any operator selected scale and skew (Figure 3).

Once the positioning system's station coordinates, the chart data, and the other survey criteria have been entered, the ECHOSCAN$^{tm}$ Survey System can then be left to run with very few operator entries.

When the survey is started, the E.S.S. dynamically updates and displays x and y coordinates, time, heading, speed and the status of the positioning system. The system automatically computes, records, and prints, as well as displays on both color monitors, the position of the vessel and the bottom cross profile revealed by returns from 32 transducers (Figure 4A & 4B). The vessel's track may also be traced on a plotter using a pre-drawn plan view plot. In addition, several soft-key code options are provided to enable the user to change certain system parameters or displays and to hold or stop the survey while it is in progress without losing data.

## OFF-LINE PROCESSING

After the survey, the data is processed by selecting and running the appropriate Post Survey Program. Like the On-Line Survey Program, operator inputs are menu driven and prompted for ease and clarity.

### Views

Various options are available for editing and plotting the survey data, the first of which is the choice of viewing perspective. It is possible to view and edit the vessel track as well as the depth profiles.

Track View: Allows the operator to smooth the selected track line and eliminate some of the effects of noisy positioning (Figure 5).

Longitudinal Profile: The user is free to select the number of transducers he wishes to see displayed simultaneously in profile along the direction of the survey track (Figure 6).

Cross Profile View: The profile seen across the track created by 32 transducer returns is displayed on the screen

for a range of records (Figure 7).

In all cases, the operator is free to select the line number, the range of records (by defining start and end records) and the number of transducers to be viewed. Additionally, a hard copy of the screen can be taken off the printer at any time. If the edit option is selected in the above examples, then data can be deleted and/or modified by moving the cursor over the screen to the desired point.

Plotting

The Plot Window: All depths are plotted using the plot window concept to ensure that all indicated soundings are legible and sufficiently spaced so that adjacent soundings (both longitudinally and horizontally) do not overlap. The plot window width is a function of the number of transducers, their spacing, and the plot scale selected. The plot window length is determined by the operator who selects the printline interval.

Depth and Strike Plots: Using the plot window concept, the Depth Plot (Figure 8a & 8b) draws the operator selected average or minimum depth observed in each window. The Strike Plot differs in that it annotates any elevations found above the project depth level.

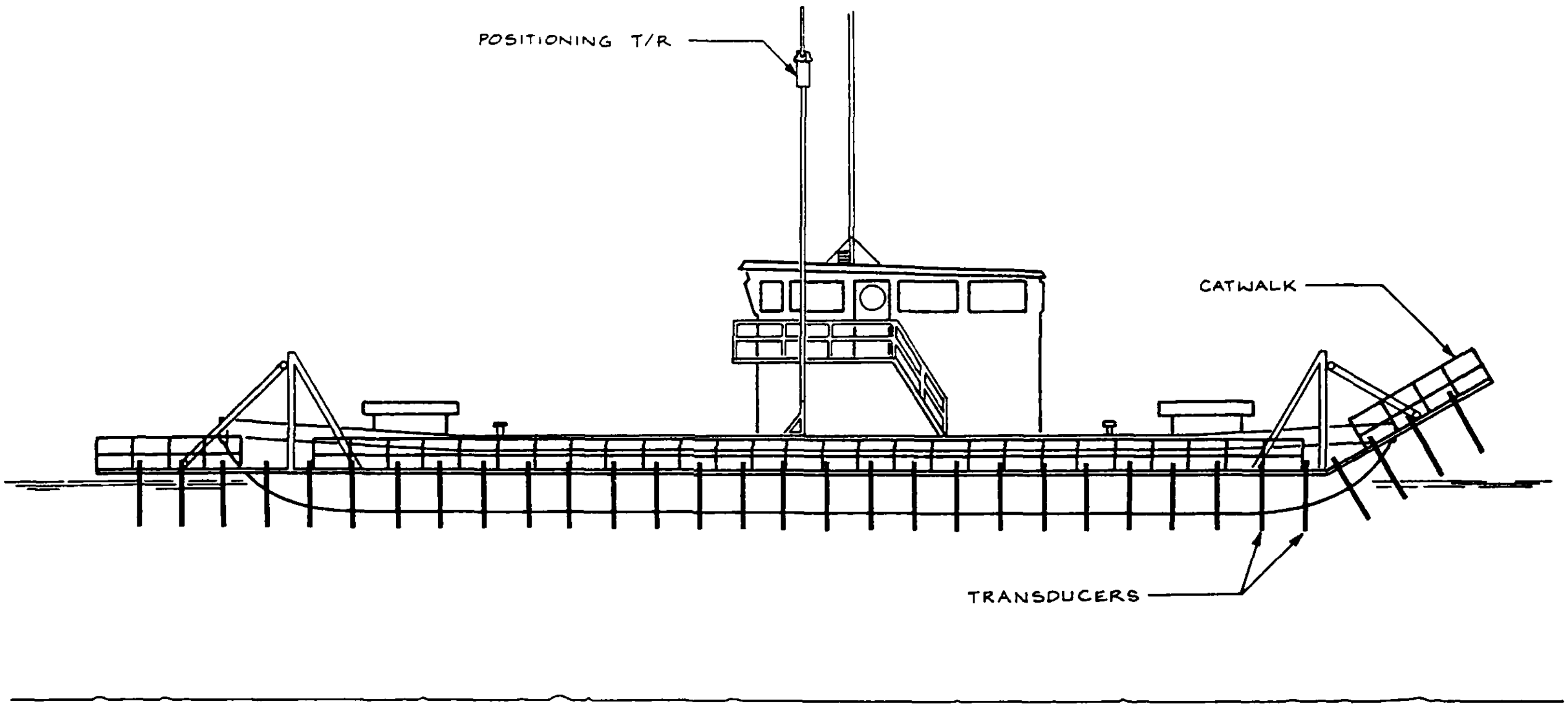
Values can be plotted in either one color, or a six-color chart can be drawn with each color corresponding to a particular depth level.

Bottom Map: Unlike the Depth and Strike Plots where numerical values are printed in different colors, solid colors are used to produce a Bottom Map mosaic on the color CRT or plotter. A black and white Bottom map can be produced by the computer printer or the external printer from a monochrome screen dump routine using a grey scale (Figure 9). This map is particularly useful in obtaining a graphic record of the collected depths and examining actual bottom coverage.

## SUMMARY

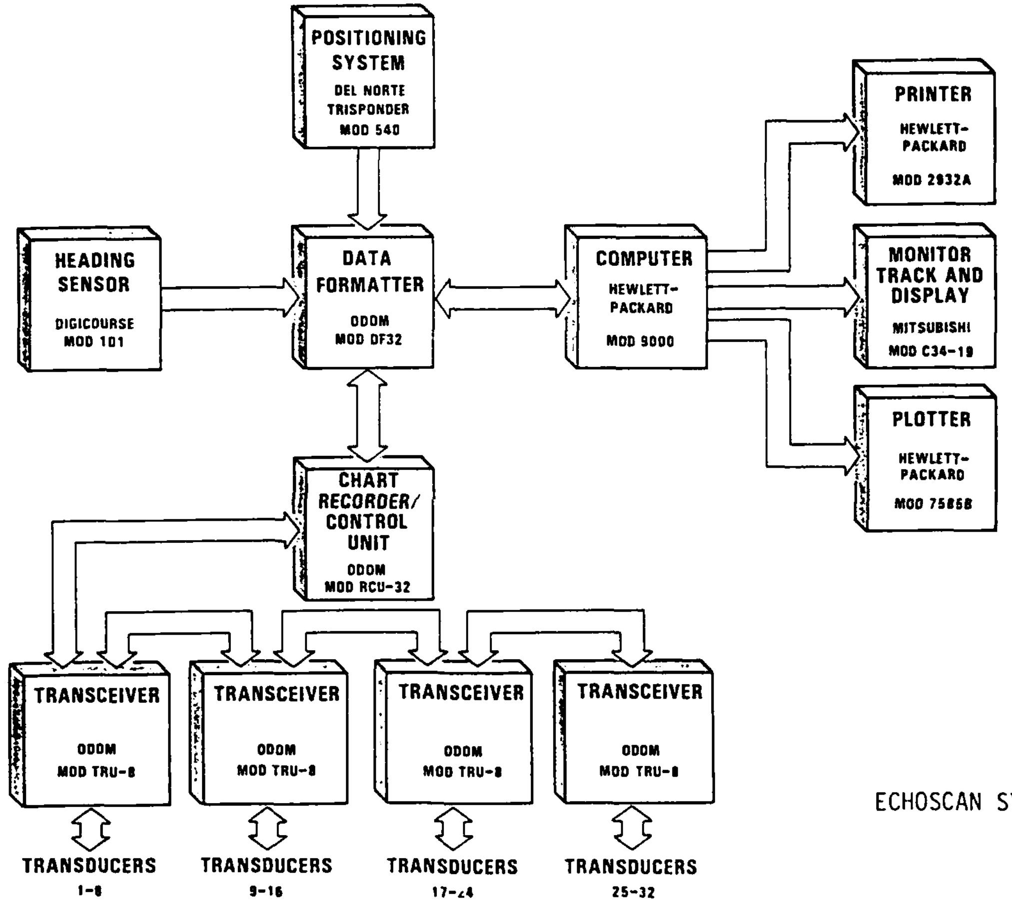
The ECHOSCAN$^{tm}$ will record cross profiles perpendicular to the vessels sailing directions. Extensive viewing and editing facilities ensure valid data for processing. The resulting charts and Bottom Maps will make obstructions easy to detect.

The ECHOSCAN$^{tm}$ systems described were delivered to the Detroit District's specifications. However, the system is very modular and can be configured to the customer's requirements. For instance, a portable system is available consisting of eight transducers mounted on a detachable, free-floating, 30 foot boom which is towed ahead of a 20 foot survey vessel. One Transceiver Unit, Recorder, and a simplified computer system provides a practical small boat sweep package for harbor and river surveys.




MULTI-TRANSDUCER SWEEP SURVEY BARGE

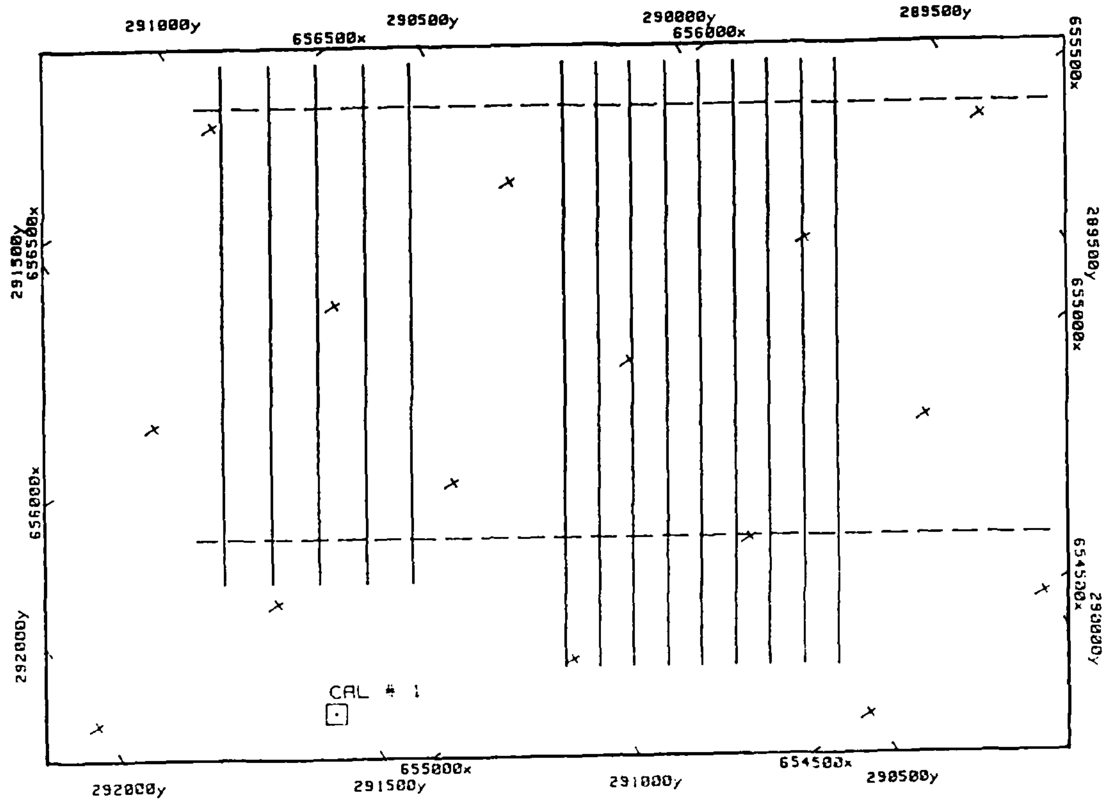
Figure 1




ECHOSCAN SYSTEM BLOCK DIAGRAM

Figure 2

PLAN VIEW PLOT OF AREA FORT WAYNE SURVEY ID FW

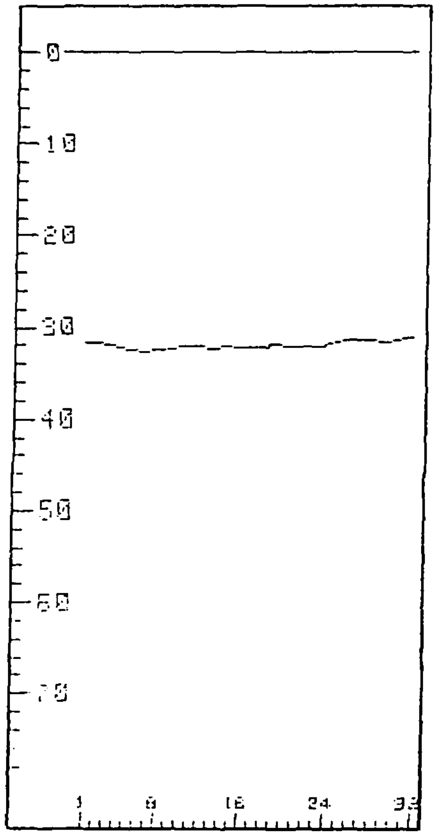



YREF:292150 Y-AXIS:1650 SCALE:300 SKEW:124

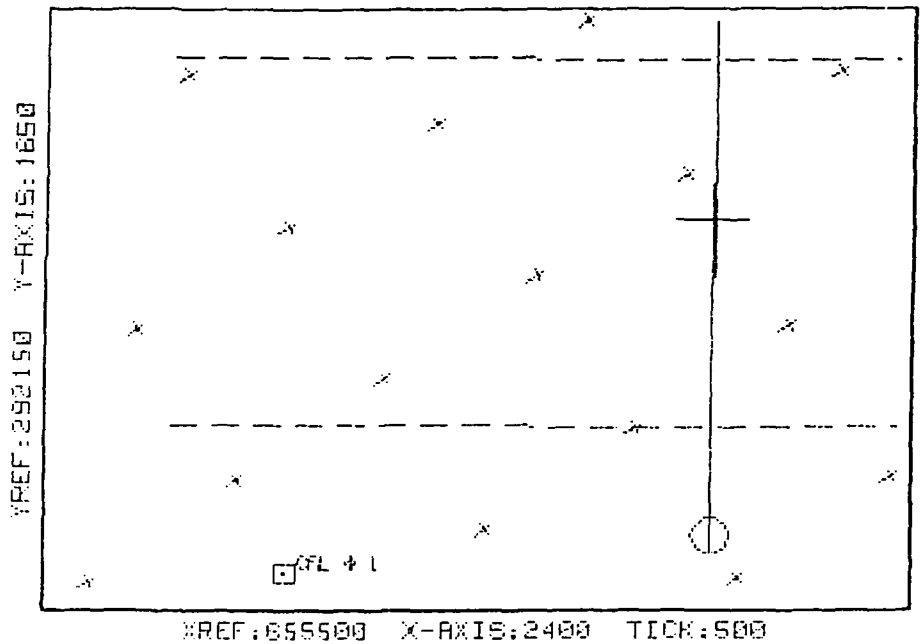
XREF:655500 X-AXIS:2400 TICK:500 DATE:12 Dec 1984

PLAN VIEW PLOT

Figure 3

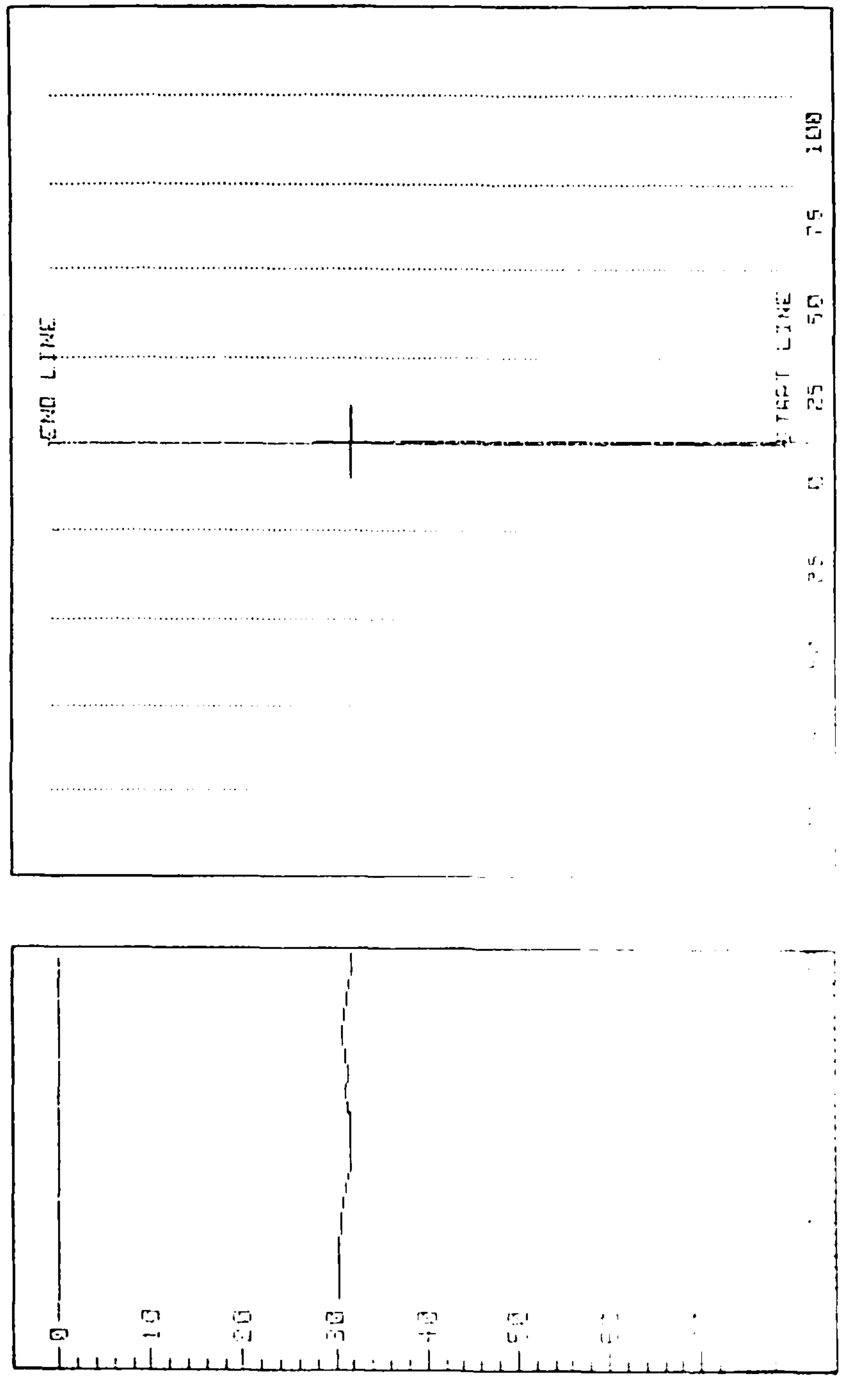



DEPTH CROSS PROFILE

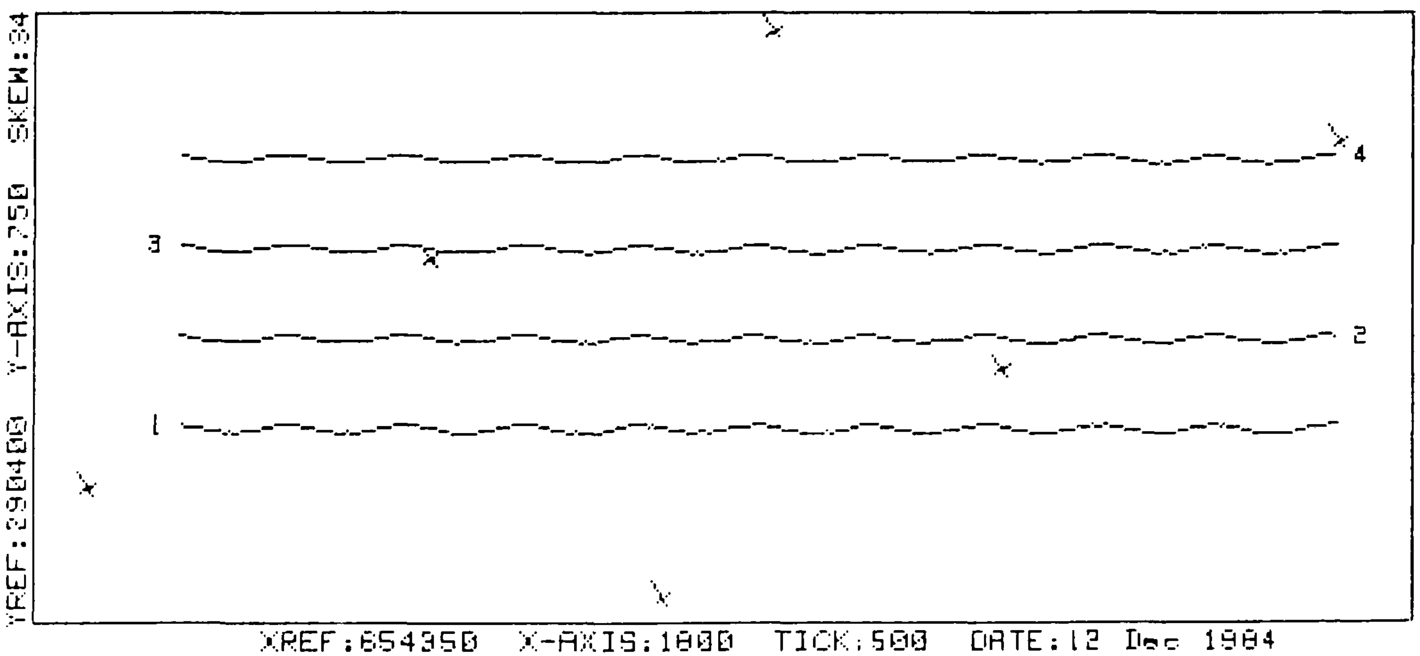



VESSEL TRACK

Figure 4a

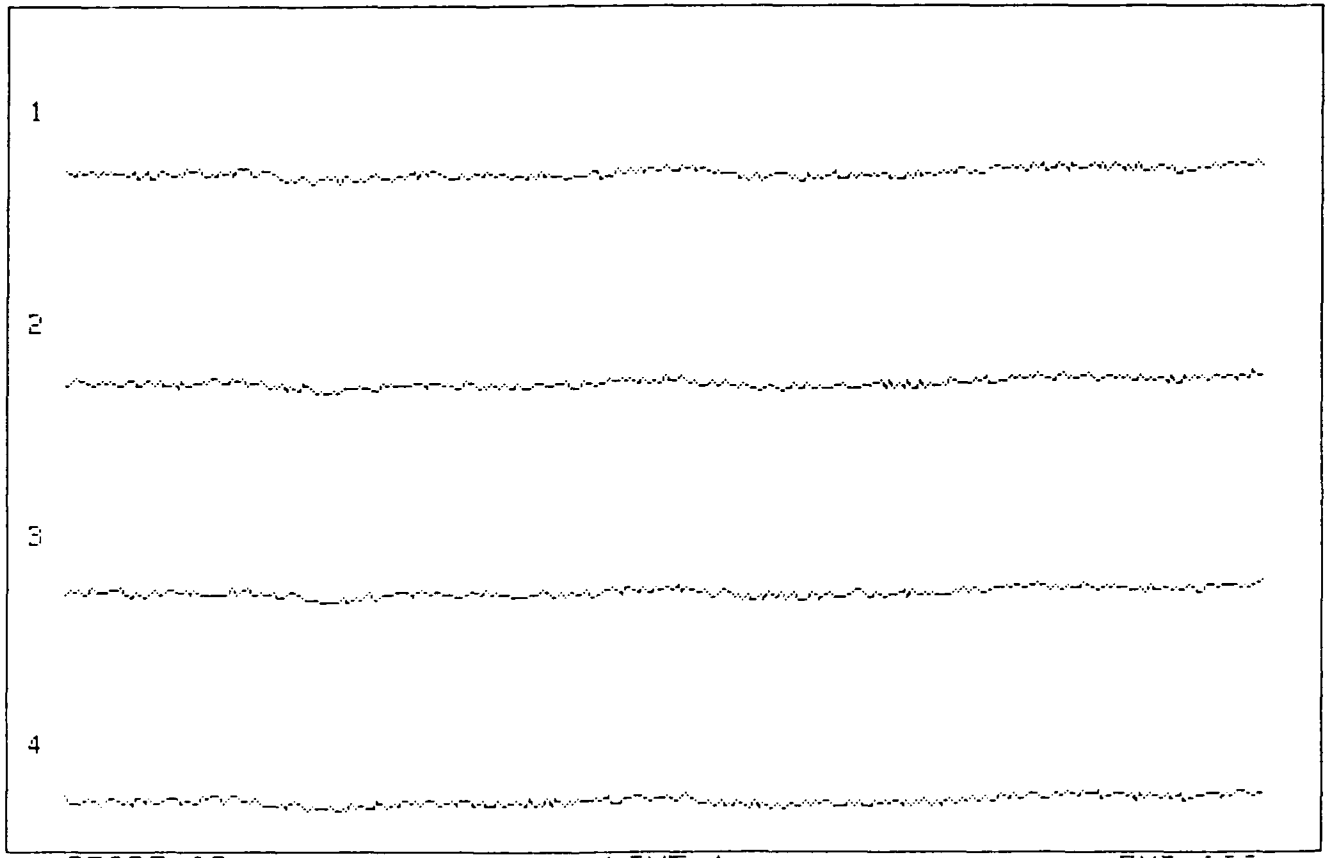



VESSEL TRACK



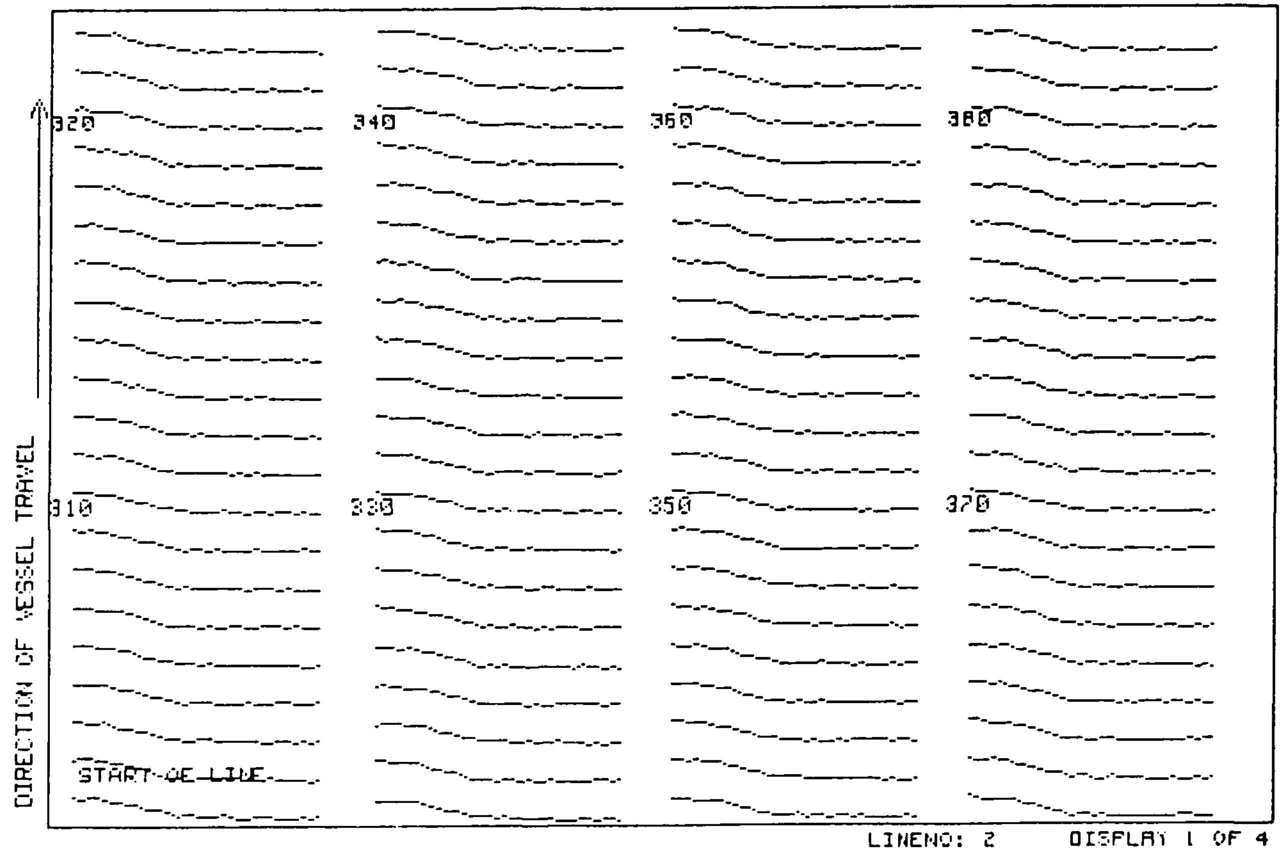

TRACK VIEW (FOR EDITING)

Figure 5




LONGITUDINAL PROFILE VIEW

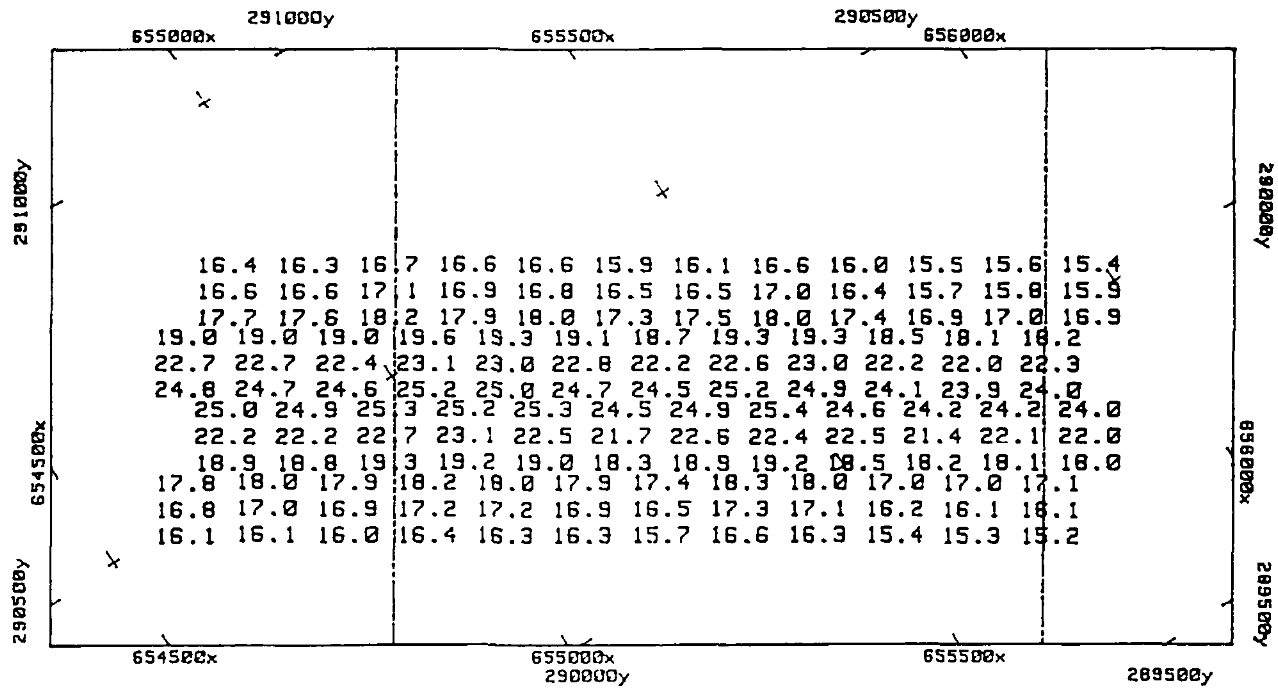
Figure 6




CROSS PROFILE VIEW
Figure 7

MINIMUM DEPTH PLOT OF AREA FORT WAYNE SURVEY ID FW1 INTERVAL:120 WIDTH:40

YREF:290450 Y-AXIS:900 SCALE:225 SKEW:34



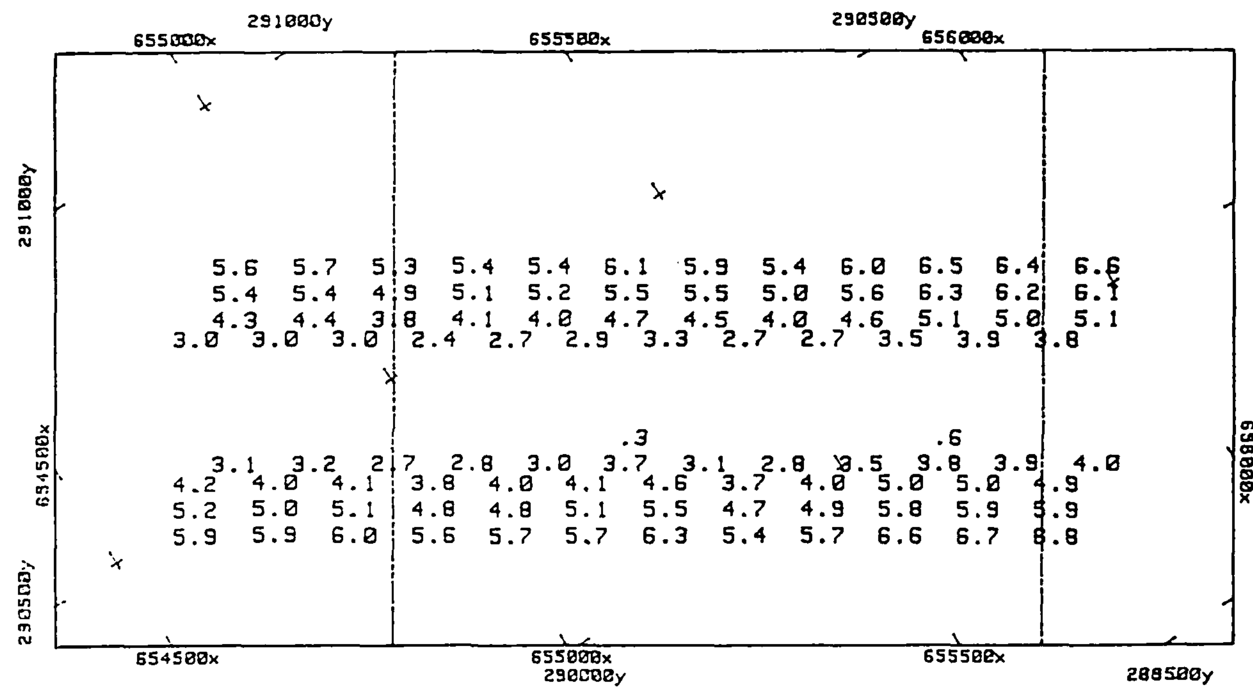

XREF:654350 X-AXIS:1800 TICK:500 DATE:12 Dec 1984

MINIMUM DEPTH PLOT

Figure 8a

STRIKE PLOT OF AREA FORT WAYNE SURVEY ID FW1 PROJECT DEPTH:22

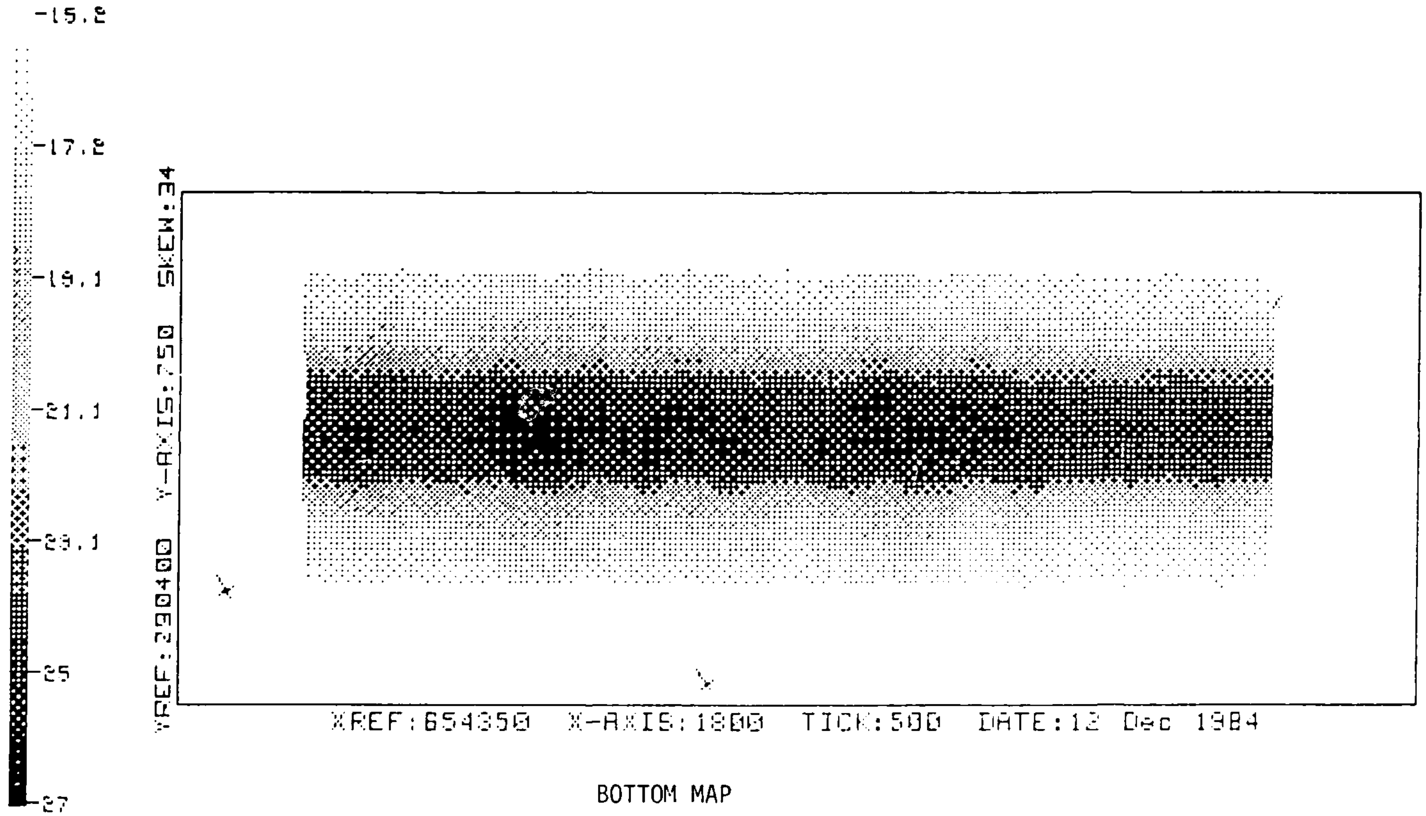
YREF:290450 Y-AXIS:900 SCALE:225 SKEW:34




XREF:654350 X-AXIS:1800 TICK:500 DATE:12 Dec 1984

STRIKE PLOT

Figure 8b




BOTTOM MAP

Figure 9

ROSS LABORATORIES, INCORPORATED
3138 FAIRVIEW AVENUE EAST
SEATTLE, WASHINGTON 98102
(206) 324-3950

# AUTOMATED SWEEP SURVEY SYSTEM

## FROM SURVEY SET-UP THROUGH FINISHED CHARTS

This paper will describe a Fully Automated, 16 Channel Depth Survey Sweep System designed and manufactured by Ross Laboratories and owned by the Canadian Department of Public Works in Vancouver, Canada.

The system has a 75 foot wide sweep. An area of 500 by 1000 feet can be surveyed in just two hours, collecting two complete sets of all channel data each second. The data can be edited and processed and charts actually produced in another two to three hours.

The transducers are mounted on two custom designed hydraulically actuated mechanical booms that are lowered over the water during survey and stored vertically when not in use. The struts holding the transducers are self-righting and will reposition themselves if hit by debris in the water. Each boom has seven transducers, plus two in the hull to make up a total of sixteen channels.

The ROSS Hardware is mounted in a rack on-board the survey vessel "PROFILER". This includes a transmitter, dedicated receiver and digitizer for each channel, interface, annotation generator, calibrator, and low and high voltage power supplies. A Ross analogue recorder is mounted separately on the bulkhead.

Other hardware includes a Digicourse heading indicator, a Hewlett Packard computer for data collection, a remote color monitor for vessel guidance, and a small Hewlett Packard plotter for showing track lines. The main computer and large E size plotter is located in the Division's main office where editing, post-processing and chart production is accomplished.

Positioning data in the particular system is provided from a Motorola Mini-Ranger III.

The ROSS Software provides complete programs for (1) Set-up, (2) Run Survey, (3) Edit Survey, and (4) Plot Survey. Each menu has its own prompts throughout the program enabling the operator to follow through the entire operation answering computer-posed questions in plain English.

The Editing Program provides both manual and automated editing.

The Plot Survey Program will produce a variety of charts. These include depths, minimum depths, contours, color plots, profiles, three-dimensional views, quantity measurements and combinations of the above. Selected charts can be produced to chart scale, survey scale or any operator scale.

The talk will be accompanied by numerous slides of the booms, ROSS Hardware, video monitor during vessel guidance and reproductions of many of the charts produced by the system.

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SEATTLE, WASHINGTON 98102
(206) 324-3950

## Biographical Sketch - Wayne M. Ross

Prior to forming his own company in 1954, Wayne M. Ross was Chief Engineer of a newly formed division of Minneapolis Honeywell, the Marine Equipment Division. Here he was responsible for further development of one of his early patents the "Sea Scanner", as well as setting up programs for other ultrasonic and acoustic projects.

At Ross Laboratories, Wayne Ross has been personally involved in designing many of its acoustic products, from the first low priced Portable Depth Finder for the sportsfisherman to sophisticated systems for marine biological studies and depth survey. Mr. Ross holds numerous patents in the field of marine acoustics.

SWATH VESSEL TEST & EVALUATION

Jack Bechly
Portland District, Corps of Engineers, U.S. Army
319 S.W. Pine Street
Portland, Oregon 97208

## BIOGRAPHICAL SKETCH

Jack Bechly is Chief, Waterways Maintenance Section, Navigation Branch, Operations Division, Portland District, Corps of Engineers. He is a BS graduate in Civil Engineering from Seattle University. Since graduation in 1959, he has been with the Corps of Engineers in Seattle and Portland Districts. After several years in comprehensive planning, he has worked with the Channels and Harbors O&M program since 1968.

## ABSTRACT

As a preliminary to Corps procurement of a SWATH type vessel for use in hydrographic surveying, the Portland District was asked to lease an existing vessel and observe its operating capabilities on the North Pacific Coast in Oregon. This paper provides a description of the SWATH concept and some early observations at the completion of the lease period in December, 1984.

## INTRODUCTION

Corps of Engineers is in the planning and evaluation phase of high speed hydrographic survey vessels for use, primarily at this time, along the East coast. Essentially, there are six types of craft suitable for high speed. First, there is the planing hull. Forward movement of the planing hull generates lift which reduces the wetted area of the hull and allows the craft to travel quickly. Second is the catamoran which incorporates two separate relatively thin hulls joined by a wide deck. Thin hulls offer lower resistance than the wider displacement planing boats. The third type of fast boat is the SWATH. This is a semisubmersible hull form which a Small Water-Plane Area Twin Hull reduces wave making resistance to allow high speed. Because the hull is isolated from surface waves to a degree, the ride can be smooth. Fourth type is the hydrofoil which uses computer controlled submerged foils to smooth out the ride. This concept is extremely expensive but seems to be acceptable in terms of improved performance. The fifth type is the hoover-craft. This vessel obtains its lift from a fan generating a cushion of air and can generally attain speeds higher than the hydrofoil, but is more susceptible to sea surface conditions and drift. One of the major advantages of the hoover craft is its land roving ability which can simplify terminal arrangements. Sixth type of vessel is a hybrid between a catamoran and the hoover-craft. Portland District currently utilizes both the displacement hull and hybrid types craft for our hydrographic surveys operations.

Before undertaking the acquisition of any of the above noted high speed vessels for hydrographic survey operation, a committee of the Marine Engineering Board was formed to prepare an evaluation of the SWATH concept and make recommendations whether it would be a practical alternative to the existing survey craft used by the Corps. As part of this committee's deliberations, the Portland District arranged for the lease of a 64 ft. SWATH vessel "Suave Lino". The vessel is normally berthed in the San Diego area. As part of the lease agreement the vessel proceeded to the

Portland District in late September, visiting the San Francisco Bay and Humbolt Bay areas in Northern California. It arrived in Portland District on the Southern Oregon Coast in early October, 1984. Under the direction of the Portland District Hydrographic Survey Branch, it proceeded to several smaller coastal projects and then arrived at the Columbia River entrance in early November, 1984 where the remainder of the test and evaluation program was accomplished. The vessel was released and returned to San Diego in mid-December, 1984.

## SWATH CONCEPT

The characteristic of all SWATH designs is two submerged hulls which provide the primary displacement. Since the two hulls are submerged, way making drag is reduced. The lower hulls are attached by surface-piercing streamlined struts that provide stability for pitch and roll and support the deck platform or upper hull higher above the water surface to minimize wave impact and deck wetness. Small Canard fins are attached to the lower hull for increasing the dynamic stability. These fins are either computer controlled to maintain a preset pitch and roll attitude or are manually operated.

## CURRENT DEVELOPMENT

SWATH vessels have been constructed and actively operated for at least the last ten years. There are several SWATH vessels up to 350 tons displacement operating in commercial service in Japan. The U.S. Navy has a 95 ft. SWATH vessel operating in the Hawaiian Islands. Several other private firms in the United States have launched SWATH vessels of various shapes and sizes. In addition to the Corps of Engineers, the concept is being actively evaluated, but mostly in larger configurations, by the U.S. Coast Guard and the U.S. Navy Department.

## PORTLAND DISTRICT PROGRAM

Purpose of the Portland District testing program was to enable the evaluation of a SWATH vessel of size similar to that invisioned for Corps of Engineers use in the winter months in the higher sea states available along the coast of Oregon. Lease of the vessel for a several month period during the fall and early winter months also enabled Portland District to accomplish head-to-head operation of the vessel with a 26 ft. displacement hull; a 65 ft. displacement hull and a 48 ft. hybrid vessel. Various representatives from interested Corps Districts and the U.S. Navy observed the SWATH at various times during the operational period along the Oregon Coast and in the Columbia River Estuary. The Boeing Company, also evaluated the pitch, roll and vertical motion characteristics of the vessel.

## SUAVE LINO

This vessel is 64 ft. in length and 30 ft. in beam. A graphical illustration is shown in figure one. The Sauve Lino has a cruising speed of 15 to 18 knots. It is powered by two diesel engines with Z drive units and propellers on submerged torpedo shaped hulls. Being constructed primarily as a sport fishing vessel, its rudder area is small and its turning radius at cruising speed is unusually large.

## PRELIMINARY EVALUATION PROGRAM RESULTS

At this writing we are phasing out the evaluation of the vessel in the Columbia River Estuary and will be returning it to San Diego in the near future. In addition to operating comparisons with our existing hydrographic survey craft, we accomplished video taping of those comparisons

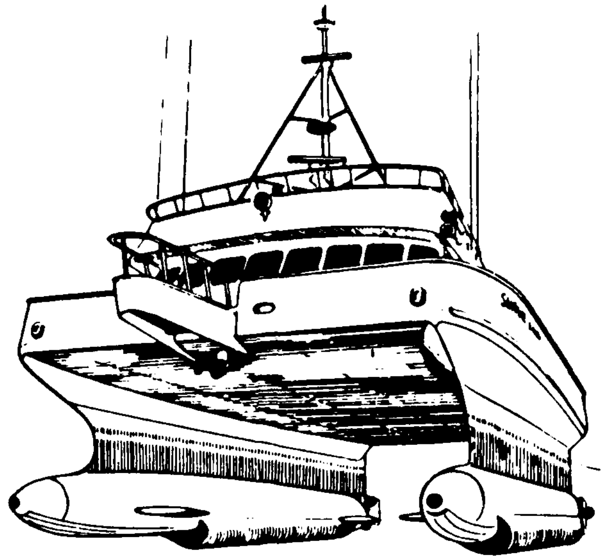

Figure 1

and will have available the written evaluations of the visiting parties for consideration in the overall decision making process. The Marine Design Center in Philadelphia will determine the direction to follow in our search for hydrographic survey vessels to perform the Corps' mission in selected areas. The video tape produced as a result of the Portland District program will be shown at the conference in February. We hope to have available the concept design document for handout. Preliminary test results from the Boeing Company on pitch, roll, yaw and vertical motion are summarized in figures 2, 3, 4 and 5 for the Suave Lino, Hickson, Rodolf and a Boeing Hydrofoil.

Generally, the SWATH type concept is very impressive in sea keeping capability. Because of the smaller water plane area of the vessel, passing waves produce only a fraction of the motion experienced by a conventional displacement hull. Also, what motion does occur can be further reduced when the SWATH ship is underway by use of the active fin controls. Furthermore, since the draft is greater than that of a displacement hull and the flow to the propeller is more uniform there is a tendency toward less propeller cavitation and quieter, more efficient operations. It was essentially able to traverse the Columbia River bar and estuary at will, whereas the 65 ft. displacement hull vessel HICKSON was often limited. One has a feeling when riding in a SWATH vessel in a severe wind chop and small swell condition that he is hoovering above the water at low level in a helicopter. There is no distinct feeling of actually being in a floating craft. This is especially true when vessel maintains a 15 to 18 knot speed necessary to fully utilize the gyroscope controlled fin system forward and aft on the submerged hulls. These fins allow the vessel to be "flown" underwater within a several foot vertical band to smooth out the swell motion. Even when riding parallel to severe wind chop or swell the inertia provided by the submerged hulls resulted in essentially a straight path.

The ability of the fin system to dampen the wind chop or swell motion of the vessel presents a special challenge for adaptation of this concept to hydrographic surveying use. Since the vessel is literally changing its datum plane every second in relation to the water surface, the ability to provide constant knowledge of the datum of the surveying transducer is impossible without further instrumentation. A device would have to be provided for hydrographic surveying use that will determine the transducer elevation relative to the water surface.

SUAVE LINO CONDITION S–4
13 NOV 84 13:44
HEAD SEA, RMS WAVE HEIGHT = 1.248 FT.
NEAR BOUY 8, COLUMBIA RIVER BAR



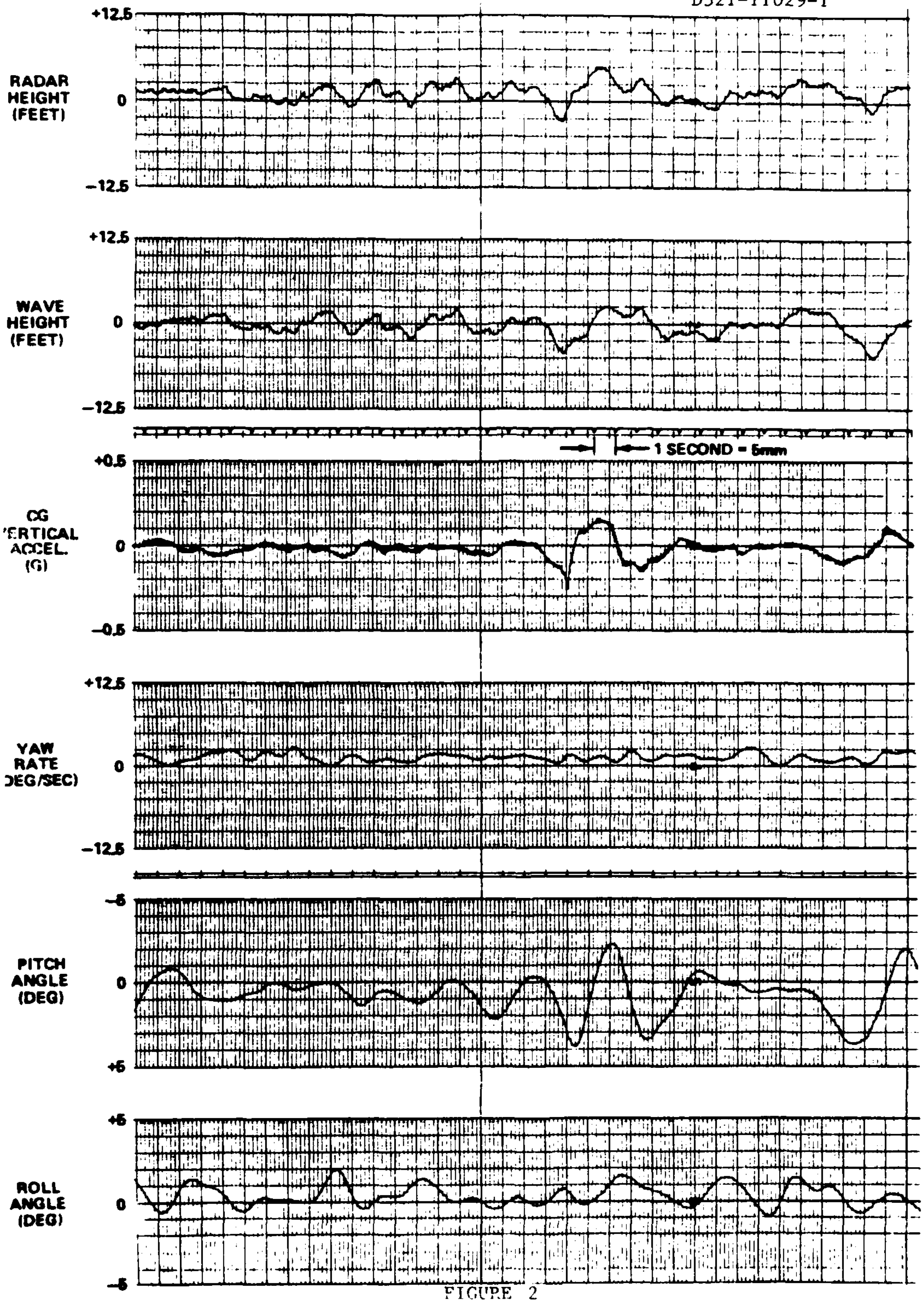


FIGURE 2

HICKSON CONDITION H-1
14 NOV 84 11:06
HEAD SEA , RMS WAVE HEIGHT=1.24 FT.
NEAR BOUY NO. 11, COLUMBIA RIVER BAR

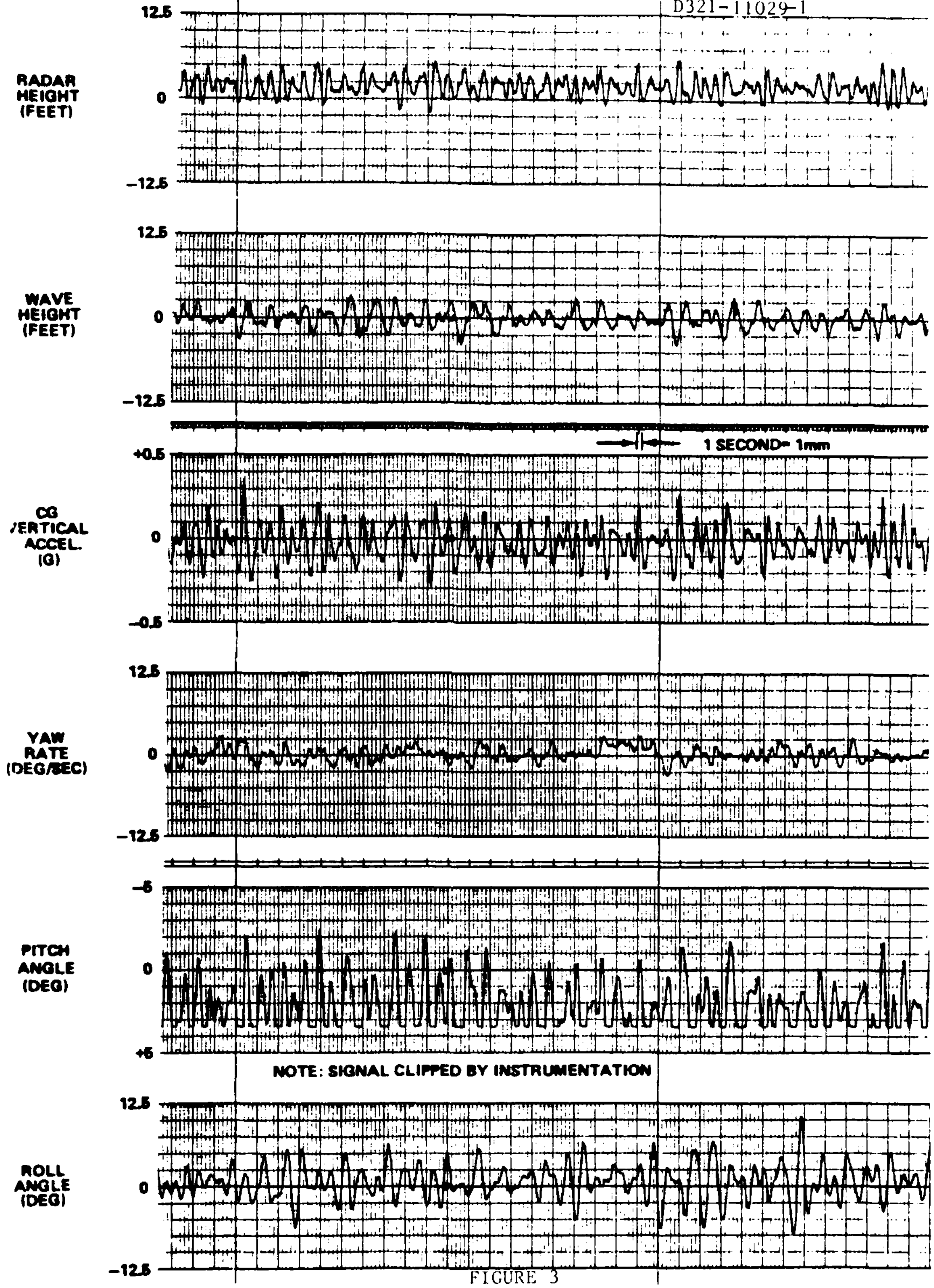


FIGURE 3

THE BOEING COMPANY

RODOLF CONDITION R–9
15 NOV 84 12:26
HEAD SEA, RMS WAVE HEIGHT = .[illegible] FT.
NEAR BOUY NO. 4, COLUMBIA RIVER BAR



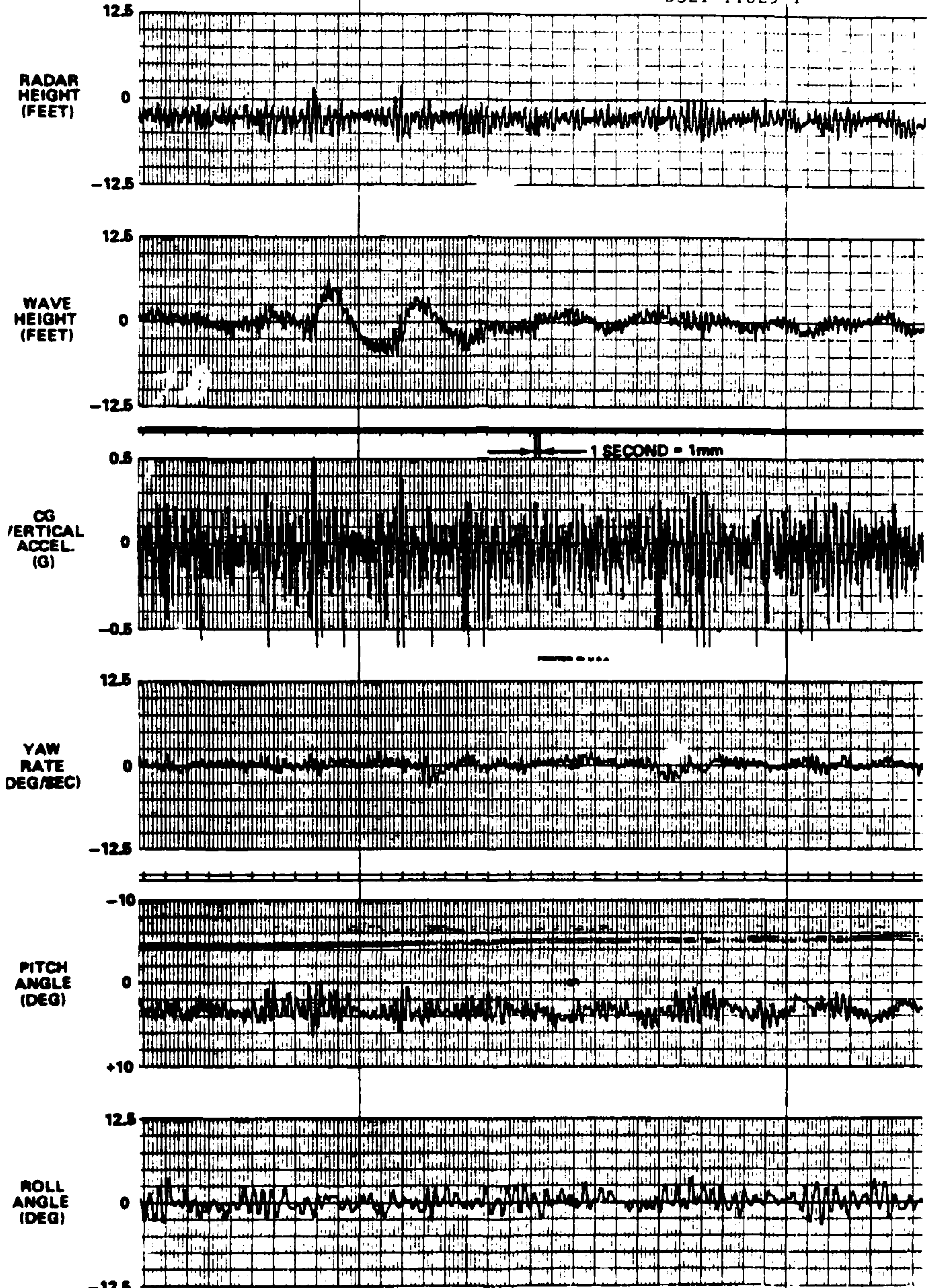


FIGURE 4

JETFOIL 17 "ARIES"
01 FEB 84 13:17:00
HEAD SEA RMS WAVE HT = 1.66 FT.
SPEED = 42 KNOTS
STRAIT OF JUAN DE FUCA

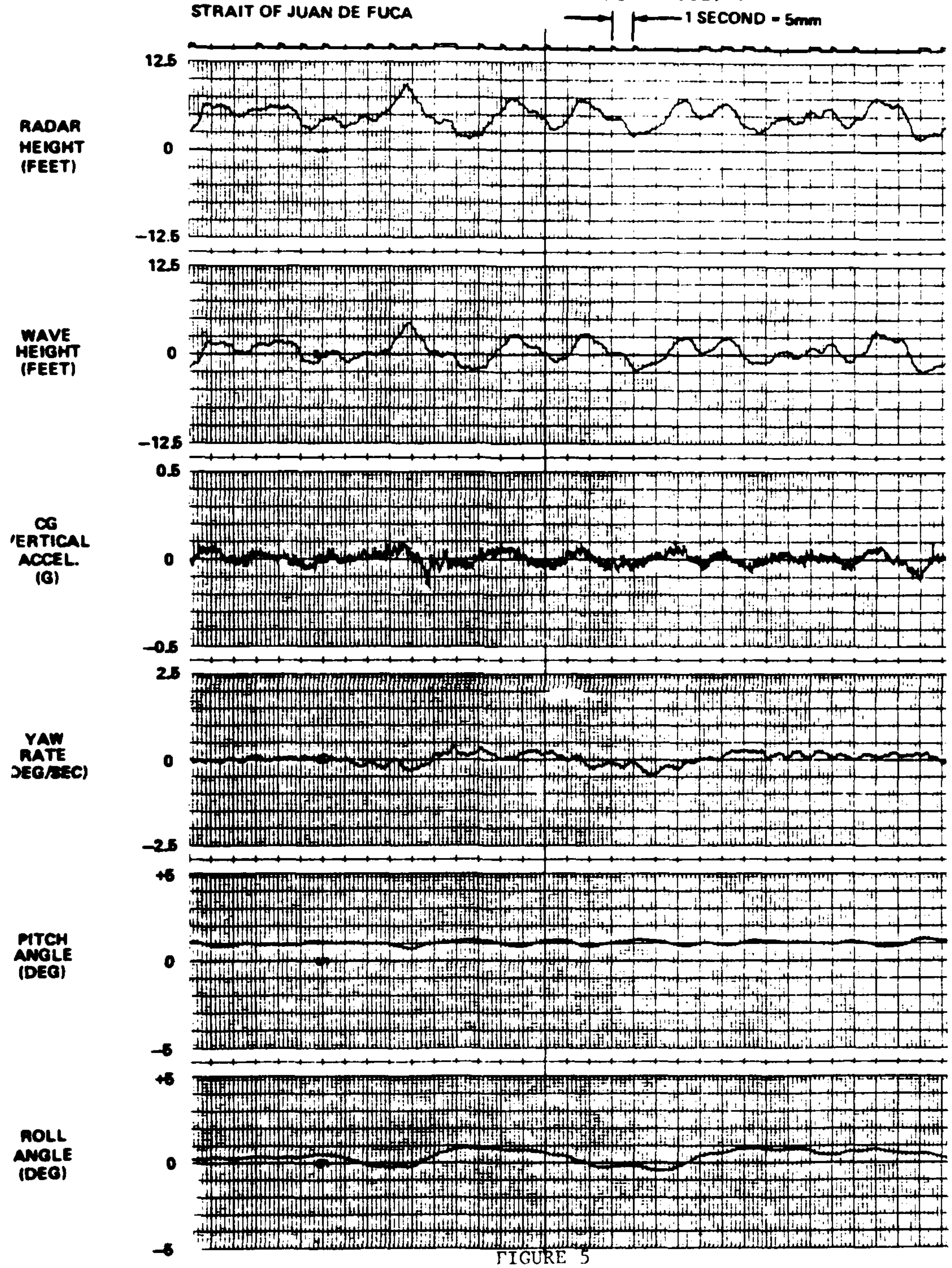


FIGURE 5

Another major problem with the current SWATH concept is its inability to turn sharply at high speed. This is generally true in all catamoran type vessels whether SWATH type or conventional displacement hulls. Utilization of this concept for hydrographic surveying will require large rudder areas and/or thrusters, to provide quick manueverability for accumulating line miles of hydrographic surveying data.

Our impression in the Portland District is that in severe wind chop and moderate ocean swell condition, it will be able to provide full surveying capability whereas this capability is now severely impaired or not possible at all. This would result in an overall increase of 20 to 30 percent in the line miles of surveying capability for coastal areas.

It would also reduce the waiting at some coastal ports for favorable ocean conditions to move the hydrographic survey craft that are not trailerable, such as the HICKSON, from one coastal entrance location to another. Many days of additional surveying time would be saved because we feel the SWATH type concept with at least 65 ft. or greater length would provide us almost unlimited sea transport ability during the spring, summer and fall months, and increase sea traversing capability during the winter months. In fact, at the present time, we simply do not leave the Columbia River entrance with the HICKSON during the months of October through March. It is likely, if we went to another coastal entrance for surveys, we couldn't get back to the primary operation area of the Columbia River for up to several weeks.

## FUTURE CONCEPT

The Sauve Lino as evaluated in the Portland District was constructed with two nearly uniform torpedo shaped hulls. Most other SWATH vessels constructed have that type of hull configuration. However, on the drawing board at both the U.S. Navy and the Coast Guard and in industry are hull designs that take advantage of improved technology to provide for more speed, more efficient operation and more successful utilization of the concept for sea keeping ability. These designs will result in shapes that are radically different from the uniform torpedo shape. Several designs undertaken have varying locations for their power plants. The Suave Lino has two diesel engines on deck with Z drives to the propellers. Vessels are being designed that have diesel engines within the submerged displacement hulls or with diesel engines on deck with chain drive systems. Since the state of the art is rapidly developing and improving with every design and construction of a SWATH vessel it can be anticipated that the concept is only in the embryo stages of development and more intriguing vessels will be available for evaluation in the near term future.

## SUMMARY

Portland District operates the 65 ft. aluminum displacement hull HICKSON as our primary large ocean entrance and Columbia Estuary hydrographic surveying vessel. This vessel has been entirely satisfactory since it was delivered to the district in about 1970. The HICKSON is still in good condition and will provide several more years of efficient and successful service. However, as noted, a vessel with a SWATH concept with similar length to the HICKSON would provide us with more months of overall hydrographic surveys availability. It would allow us to survey some projects during winter months which now is impossible. The Columbia River Bar is a notable example of this desirable capability. We feel that the replacement for the HICKSON at some future date will be a SWATH type vessel of the state-of-the-art currently being developed by many varying interests. One ride on this vessel during a 35 knot wind in the Columbia River Estuary will convince most parties of that conclusion.

# IMPROVING SURVEY PERFORMANCE WITH SWATH BOATS

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BIOGRAPHICAL SKETCH

Scott Drummond is Vice President, Eastern Operations, for SEACO Incorporated. He has been actively engaged in SWATH boat programs for the last five years with SEACO. In his Navy career he has participated in hydrographic and oceanographic surveys, and was the Director of the Defense Mapping Agency Hydrographic Center.

ABSTRACT

The small waterplane area twin hull (SWATH) designed boat offers the hydrographer many operational advantages over the monohull boat. This paper describes the better sea keeping qualities of the SWATH and how these may help the hydrographer do his job faster for less, and get better quality data.

INTRODUCTION

The demand for hydrographic data and nautical charts always seems to grow. As ships get larger and the clearance between the keel and the bottom become less, the coverage and accuracy of data must get better. As we become more dependent on ocean resources and more active in ocean exploitation, more data will be needed. The requirement to go out and get much of this new data becomes the job of the hydrographic surveyor. However, the resources available to the surveyor do not seem to be getting bigger and better along with the requirement.

Faced with this situation we must get everything we can out of the tools that are available to us. One of those tools is the small waterplane area twin hull boat. With SWATH designed survey platforms you will not be as operationaly restricted by the sea state, your crews will work better and your data will be of higher quality. All of these benefits come from the better seakeeping qualities of the SWATH as compared to the monohull.

SWATH

The small waterplane area twin hull (SWATH) designed boat (Figure 1) has two parallel, submerged, torpedo-like lower hulls which are attached, by hydrofoil-like struts, to a platform or upper hull which is located well above the surface.

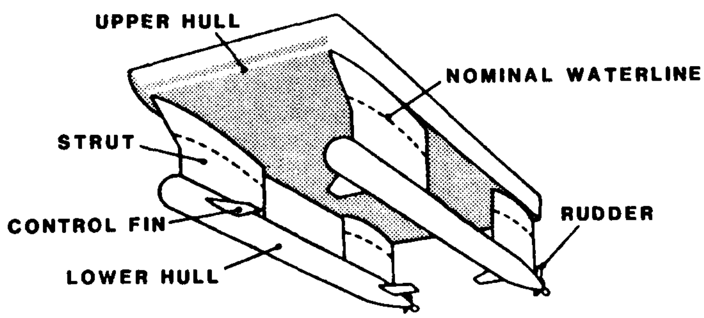



Figure 1. Suave Lino

of the water. Horizontal control fins are attached to the lower hulls for increasing dynamic stability and providing additional control in heave, roll, and pitch under all performance conditions. It should be noted that the SWATH is twin hulled and not a catamaran in the sense that many people think of it. SWATH should not be confused with two monohulls tied together. The monohulls have very different seakeeping qualities.

The SWATH idea has been around for a number of years with the first patents being issued over 100 years ago. The first operational SWATH boat is the U. S. Navy's 90 foot (27.4m) semisubmerged platform KAIMALINO, which was built in the early 70's.

The SWATH boat SUAVE LINO (Figure 2) is the second SWATH boat built in the U. S. Launched in 1981 as a sport fishing boat, the SUAVE LINO is 65 feet (19.8m) long with a beam of 30 feet (9.1m). Normal operating displacement is 46.6 tons, and her maximum load displacement is 52 tons. The normal operating draft is 6 feet (1.8m). Maximum speed is 20 knots and cruising speed is 15 knots. At maximum speed fuel consumption is 42 gallons per hour.

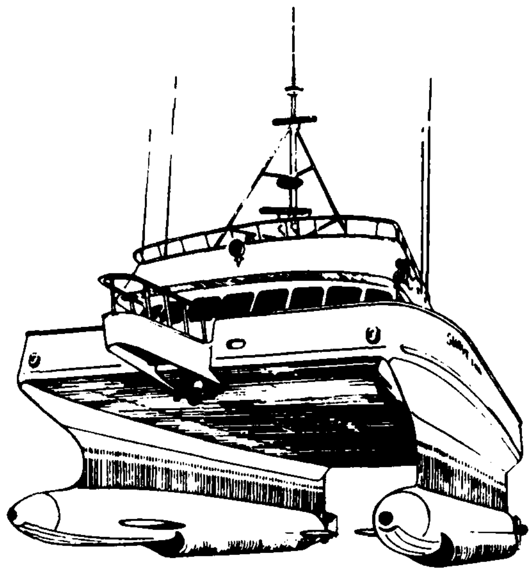
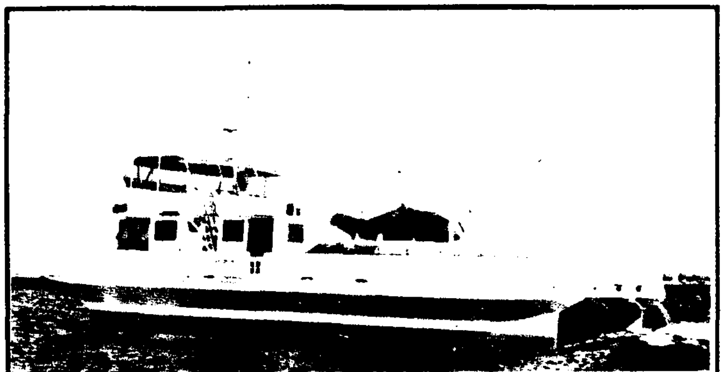


Figure 2. SUAVE LINO

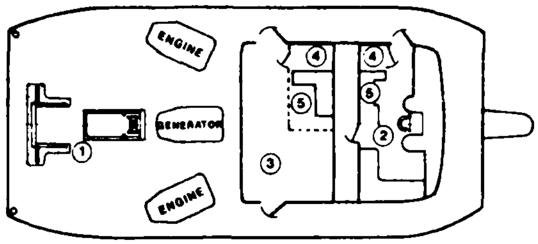
SUAVE LINO is all welded aluminum construction. The vertical struts which give the SUAVE LINO her small waterplane area are 5.6 feet (1.7m) long and about 1 foot (.3m) in thickness. The deck mounted main engines are connected to the propellers by solid shaft "Z" drives using two right angle gear boxes. They are General Motors Detroit Diesels rated at 425 horsepower at 2300 rpm. There are two generators; one 30 kw and one 15 kw. The pilot house has a well laid out control station where everything is at the fingertips of the operator. There is a second control station on the flying bridge, as well as rudder and engine controls at each side of the flying bridge. The lower hulls are 3.8 feet (1.1m) in diameter, and contain both ballast and fuel oil tanks. The total fuel capacity is 3800 gallons. The upper hull holds 500 gallons of potable water, and one reverse osmosis water maker that is rated at 350 gallons a day.

The SUAVE LINO has control fins on the inside of each of the lower hulls. These fins can be controlled by a gyro or manually. The gyro control is more responsive and provides the best ride.

The SUAVE LINO as currently configured is shown in Figure 3. This is a modification from her original design and provides excellent space and arrangement for hydrographic and oceanographic work.



The 19.8 meter Small Waterplane Area Twin Hull (SWATH) ship *Suave Lino*




① "A" FRAME ASSEMBLY
② WHEELHOUSE/MESSING
③ SCIENTIFIC SPACES
④ HEAD/SHOWER
⑤ GALLEY

Figure 3. CURRENT CONFIGURATION OF SUAVE LINO

Seakeeping tests were conducted with SUAVE LINO soon after she was launched. The reduced pitch and roll data from this test are shown in Table 1. Looking across the top you can see that the SUAVE LINO took the seas from dead ahead, on the bow, beam, quarter, and astern. Wave height ranged from 4.1 (1.2m) to 5.8 (1.8m) feet and the wind averaged 23 knots throughout the test.

Table 1. SUAVE LINO - Seakeeping Summary

| Direction of Waves | Head | Bow | Beam | Quarter | Stern | Head |
|---|---|---|---|---|---|---|
| Wave Height (Feet) | 4.1 | 4.4 | 4.8 | 5.1 | 5.4 | 5.8 |
| (Meters) | 1.2 | 1.3 | 1.5 | 1.6 | 1.6 | 1.8 |
| Boat Speed (Knots) | 15 | 15 | 15 | 15 | 15 | 6 |
| Pitch (Degrees) | 2.0 | 2.1 | 2.0 | 3.3 | 3.3 | 4.7 |
| Roll (Degrees) | 1.1 | 1.4 | 2.9 | 2.8 | 1.7 | 3.6 |

Perhaps the most telling information in the table is shown in the BEAM column. With waves of 4.8 feet (1.5m), roll was less than 3 degrees.

The column on the far right is for one run at reduced speed directly into the seas. By that time the seas were almost 6 feet (1.8m) and the wind continued at 23 knots. Under these least desirable conditions with the SUAVE LINO going 6 knots where her control fins are not too effective, roll was limited to 3.6 degrees and pitch to 4.7 degrees.

A limited comparison of the seakeeping capabilities was made between the SWATH hull form, a monohull and a catamaran (Table 2). Due to various constraints the tests were limited to zero speed in head and beam seas. The data for the monohull was obtained from model testing. Corresponding motion characteristics were calculated for the SWATH hull form using computer programs. The motion of the catamaran hull form was estimated using data from previous model tests.

Table 2. Comparison of Motions for SWATH, Monohull, and Catamaran Forms

| Hull Description | Monohull | SWATH | Catamaran |
|---|---|---|---|
| Displacement, Long Ton | 33.0 | 33.0 | 33.0 |
| LOA, Ft | 56.1 (17.1m) | 42.0 (12.8m) | 48.6 (14.8m) |
| Maximum Beam, Ft | 15.7 (4.9m) | 32.1 (9.9m) | 18.0 (5.5m) |
| | SEA STATE | | |
| Sea State Number | 2.5 | 2.5 | 2.5 |
| Significant Wave Height, Ft | 3.5 (1.1m) | 3.5 (1.1m) | 3.5 (1.1m) |
| | HEAD SEA RESULTS | | |
| Peak Pitch (Bow Up), Deg. | 6.6 | 2.9 | 12.5 |
| | BEAM SEA RESULTS | | |
| Peak Roll, Deg. | 21.8 | 7.0 | 18.1 |

Data was developed for hulls of 33 ton displacement, a little smaller than the SUAVE LINO. At the SEA STATE line we can see that wave height was 3.5 feet (1.1m). Data of special interest is shown in the BEAM SEA RESULTS section, and on the bottom line of the table we can see that the monohull rolled 21.8 degrees, the catamaran 18.1 degrees and the SWATH only 7.0 degrees.

Taking these tests one step further, data was developed for the SWATH in 5 (1.5m) and 10 foot (3.0m) seas. In Table 3 we can see that at 15 knots, in 10 foot (3.0m) seas the SWATH would be rolling some 5.2 degrees. Looking back to Table 2, note that the monohull was rolling 21 degrees in 3-1/2 foot (1.1m) seas.

Table 3. Seakeeping - 42 Foot (12.8m) SWATH

| 5 Ft. (1.5m) Significant Wave Height | | |
|---|---|---|
| Pitch | 1.8° | 2.1° |
| Roll | 1.9° | 3.1° |
| **10 Ft. (3.0m) Significant Wave Height** | | |
| Pitch | 3.2° | 3.6° |
| Roll | 3.2° | 5.2° |

## CONCLUSION

What this tells us is that the SWATH boat will outperform a monohull or a catamaran of the same size. Put another way, the SWATH boat of a given size will turn in the performance of a much larger monohull. For hydrographers it means you will be able to stay on the survey line with a SWATH boat when the monohull has had to heave to or seek shelter from the seas. This loss of time can be very costly.

The Suave Lino is proving in actual underway survey situations, that the SWATH boat will perform as advertised. I do not believe it will be too long before you start seeing more and more SWATH's around. People will quickly recognize that its just plain good business.

# SESSION III: BEACH AND NEARSHORE SURVEYS

# SURF ZONE AND NEARSHORE SURVEYING WITH HELICOPTER AND A TOTAL STATION

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## BIOGRAPHICAL SKETCH

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## ABSTRACT

Accurate surveys of the nearshore ocean bottom are difficult to accomplish in high sea or surf conditions. Portland District has overcome this problem by using a helicopter-borne graduated cable and conventional survey instruments. A helicopter is fitted with an 85-foot weighted cable graduated in a manner similar to a surveyor's rod. Ocean bottom elevation to a depth of -40 feet mean lower low water is obtained by reading the graduated cable with a surveyor's level. An AGA 140 electronic total station aimed at a cluster of prisms mounted on the helicopter is used to obtain distances on an established cross-section line. Soundings are controlled horizontally by a surveyed baseline. This system allows soundings to be readily obtained in most weather conditions, with winds above 30 mph and heavy fog proving exceptions. A typical 3,000 to 5,000-foot long cross-section line can be surveyed in about 20 minutes. Field data are used for design and construction of coastal structures and for beach erosion studies. The helicopter can also be used as a sampling station for collecting sediment samples and to perform dye tests used to determine current direction near jetties.

## INTRODUCTION

Coastal engineers and surveyors working in surf with high waves are all too familiar with the difficulties of accurately surveying in such an area. Some have tried to use a boat or an amphibious buggy. Both types of equipment are limited by wave actions. High-precision fathometer surveying is almost impossible because of problems in accurately overlapping the beach and fathometer surveys, in filtering out the wave effects, and in accounting for tide changes.

This paper describes the equipment and procedures used by the Corps of Engineers, Portland District, for obtaining high-precision nearshore bathymetric surveys.

These surveys are used to:

1) Establish a quantitative data base (beach profiles, sediment characteristics, wave climate) within the study area for pre- and post-jetty extension effects comparison;

2) Predict, through the use of a numerical model, the erosion and accretion patterns within the study area that could be correlated with jetty extension construction;

3) Compare model and prototype post-jetty extension beach profiles, and longshore and on/offshore sediment transport; and

4) Determine the effects (if any) of jetty extension in terms of changes in erosion/accretion patterns of adjacent shorelines.

HELICOPTER SPECIFICATIONS

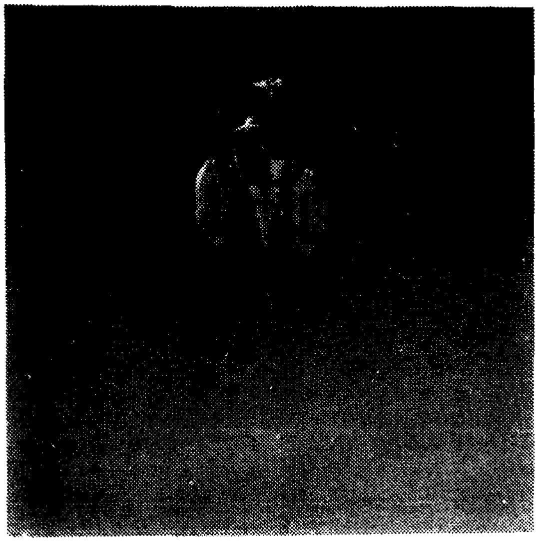

Figure 1. Helicopter and cable assembly in use on the Oregon Coast.

The helicopter (Figure 1) shall be equipped with not less than a 260 horsepower engine, flotation landing gear and an undercarriage capable of supporting up to a 150-foot survey line in a way that guarantees that no slack line will develop during the survey operation. The helicopter pilot shall hold a current FAA commercial pilot's license with a helicopter pilot rating, and possess a minimum 500 hours of flight time, including 100 hours in mountainous terrain. The contractor agrees to strictly observe all pertinent safety regulations, and see that the helicopter complies with safety regulations in force at the contractor's base pursuant to local ordinances, State law, and Federal Aviation Agency requirements.

## EQUIPMENT ON HELICOPTER

In 1960, the Portland District Survey Branch was requested to develop a method for obtaining sea floor data. This request was made in connection with planned rebuilding, improvements, and extensions of several river mouth jetties along the Oregon coast. The method developed would be used for mapping areas immediately adjacent to the jetties and surf-affected areas along beaches extending both directions from river entrances. John Hess, Survey Branch Chief, and Steve Senkovich, Field Supervisor, both now retired, undertook this challenge. Their conclusion was to do the job with a helicopter.

The helicopter cable system is composed of four parts: the main weight and leader; the main cable; the counterweight and travel cable; and the undercarriage.

The 60-pound lead ball main weight is attached with a stainless steel ball bearing swivel to a 9-foot-long, 480-pound test, stainless steel cable leader. The leader is attached by a swivel and a small shackle to the main cable. The leader cable can be easily replaced if broken. A large supply of lead balls and leader cables is kept on hand.

The main cable is composed of many parts. It is a 5/32-inch, 2,400-pound test, stainless steel aircraft-type cable. Four-inch-square numbered wooden blocks are fitted onto the cable by hand at 10-foot intervals. At 1-foot intervals between the blocks are eight golf balls in a repeating color code. A larger cork ball marks each 5-foot interval. Between the golf balls at the 1/2-foot marks are large oval lead sinkers. This cable is used in the same capacity as a standard level rod. It is observed from shore through a Wild NA 2 level.

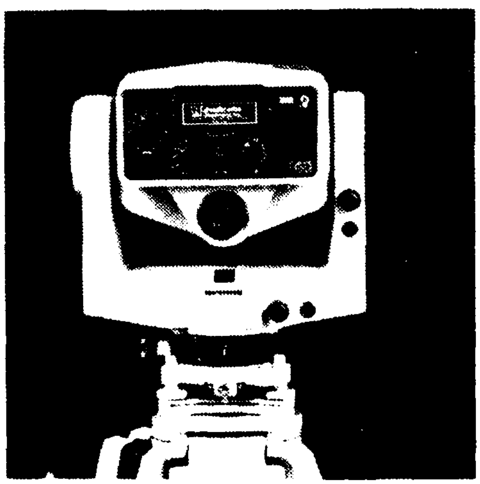

Figure 2. AGA 140 Electronic Surveying Instrument.

Most of the helicopter work is done with a 60-foot main cable, with 10 feet of leader and the weight attached. This allows a maximum depth of about 50 feet with 20 feet of line still visible for readings. In deeper water, extension sections are attached to the main cable.

The main cable is attached by shackles to a travel cable running to the counterweight over two pulleys on opposite ends of the carriage boom. The counterweight is attached with a swivel and shackle. Cable stops on the carriage allow the counterweight to travel about 6 feet.

The carriage assembly is a simple, but very important, component. It consists of a metal tube or angle iron structure about 10 feet long with a rear cross-member. Brackets on the crossmember fit against the bottom of the helicopter's rear skid axle. A metal loop on the boom attaches to a cargo hook on the aircraft's belly. An inflated inner tube attached to the front of the boom protects the bottom of the helicopter from any recoil action. In an emergency the entire assembly, including the cable and weights, can be dropped by simply releasing the cargo hook.

A cluster of prismatic mirrors attached to a bracket on the helicopter is used to determine shore-to-helicopter distance. Distances are measured with an AGA 140 Electronic Distance measuring instrument total station (Figure 2) which reduces the slope distance to a horizontal distance.

# SURVEY SYSTEM

To use the system, a surveyed controlled base line is established over the length of the study area. From the base line, reference marks are placed on pre-determined cross-section lines extending onto the open beach area at right angles to the overall water line. The AGA 140 total station is used to determine distances and elevation differences on the ground portion of the cross-sections. The helicopter system is used to gather profile information on the underwater portion of the cross-section line.

The survey crew and helicopter pilot have a safety meeting before each job begins. The crew and pilot maintain radio contact at all times. Radio contact with the U.S. Coast Guard is also available in any emergency.

The survey crew sets up their instruments at a cross-section reference mark on the beach and erects two large orange panels on the cross-section line. The helicopter pilot lines up on the orange panels and takes a position at the outer limits of the cross-section line.

When the survey crew is ready, the helicopter descends until the lead ball touches the ocean bottom. The pilot can observe the cable and counterweight in a large convex mirror placed just below and forward of the cockpit. As the main lead ball touches the ocean bottom, the counterweight drops and the pilot stops his descent. The cable jerks slightly, telling the level reader that the ball has touched ground. At that moment he reads the marking on the cable. It is quite easy to interpolate readings to the nearest 1/10-foot, because of the 1/2-foot markings. The level reading is called out and recorded in a field book. During this prodedure, the total station has been aimed at the prisms and kept operating in a tracking mode.

This gives the operator a constantly updated horizontal distance. When the level reading is called out, another crew member reads the display on the total station. That measurement is also recorded in the field book. The radio operator then informs the pilot that the measurements have been taken, the helicopter ascends, moves forward, and descends for the next reading.

It takes approximately 20 minutes to make the 25 to 30 readings needed to cover about 1,500 feet of a cross-section line. Five to 10 seconds are needed to read the level and total station, and record both measurements for each shot. The greater portion of the time required for each section is spent in maneuvering the helicopter.

We are in the process of coupling a data collector with the AGA 140 total station. This will eliminate the need for a field book.

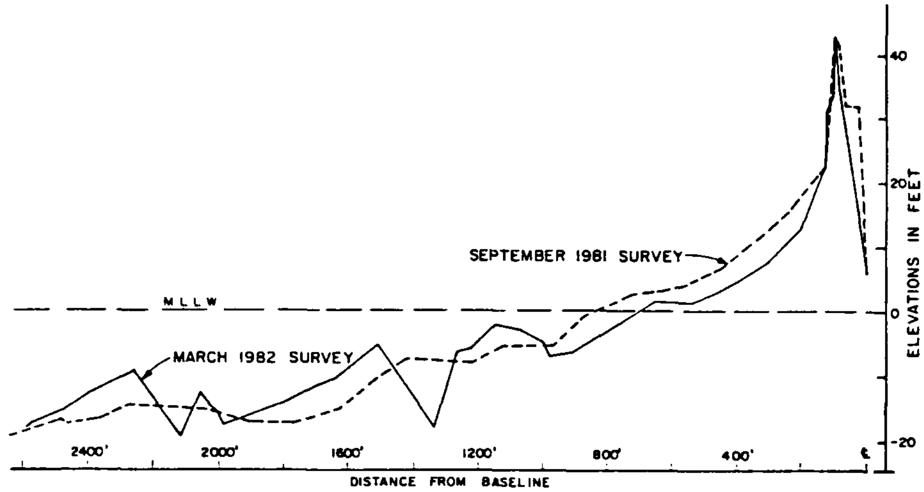


Figure 3. Comparison of cross-section using helicopter - AGA 140 system

Data analysis for studies making use of helicopter surveying methods will primarily involve prediction of shoreline changes due to jetty extensions by means of a numerical model and verification of model results with prototype measurements. Steps for data analysis include:

1) Beach profile and contour mapping
2) Sediment budget calculations
3) Model calibration
4) Shoreline simulation
5) Model verification

Beach Profile and Contour Mapping. Survey data will be entered onto the District's computer and existing programs will be used to produce beach profile plots, contour maps and 3-D representations of the study area. These will be helpful in identifying stable stretches of beach and areas of maximum sand movement.

Sediment Budget Calculations. Seasonal longshore and on/offshore sediment transport rates will be estimated by calculating the differences in beach profiles over time. Existing computer programs will be employed to accomplish this task. Results will be compared against estimates from the empirical methods described in the Shore Protection Manual.

Model Calibration. "A Numerical Model to Simulate Transport in the Vicinity of Coastal Structures" is scheduled to be used for each study. The model will be calibrated with the pre-construction and construction data

(beach profile, sand characteristics, and wave data). Criteria will be established to determine optimum model calibration.

Shoreline Simulation. Simulated shoreline changes and the period needed for the shoreline to reach equilibrium after construction will be estimated. If the simulated period for equilibrium exceeds the 3 years of post-construction monitoring, additional funding will be requested to extend the post-construction monitoring at that time.

Model Verification. The simulated shoreline will be compared to the collected beach profiles. Comparison plots of beach profiles and shoreline contours will graphically identify areas of accretion and erosion. Quantitative comparison of longshore and on/offshore sediment transport will also be made.

## SUMMARY

The helicopter and total station system provides study results needed for nearshore surveys. Over the years since its inception, it has contributed to the successful and timely completion of Portland District's mission all along the Oregon Coast. The cost of the sounding cable assembly is approximately $1,200; that of the helicopter, ±$300 per flying hour. The cost of a four-man survey crew is $1,000 per day. The system can be easily implemented wherever anyone needs deep water surveying done accurately and efficently.

## ACKNOWLEDGMENTS

The authors wish to express their thanks to the U.S. Army Corps of Engineers, Portland District personnel for their cooperation in completing all data and graphics work in a short period of time.

# A METHOD FOR ADJUSTING BEACH PROFILE LINES FOR OFFSHORE CLOSURE

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## BIOGRAPHICAL SKETCHES

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## ABSTRACT

The authors describe a proposed method to adjust hydrographic survey data measured by fathometer. The method can be applied to profile comparisons that show offshore divergence. The method holds the most recent survey data and adjusts the older survey by computing new tide and draft and speed of sound correction factors. These factors are then applied to adjust the elevation of the old survey.

## INTRODUCTION

Erosion losses in the nearshore below water often constitute the majority of measurable erosion or accretion of a beach. Beach and nearshore surveys can be compared to evaluate these volumes. The coastal engineer expects the offshore profile comparison to converge at or near a depth of closure (seaward limit of sand movement). Often convergence of the beach profile is not apparent and profiles diverge offshore. A diverging profile can indicate a survey error.

Evaluation of a theoritical closure depth can be used to resolve problems with beach and nearshore profile comparisons which do not converge offshore. Coastal engineering studies generally require a consideration of the seaward limit of wave induced sand movement along a beach profile. A method to calculate this limit was developed by Hollermeier (1981). The seaward limit varies from approximately 15 ft. to 80 ft. along the Atlantic coast, depending upon available wave energy.

Most hydrographic beach surveys consist of two parts, onshore/nearshore measurements and offshore measurements. The onshore/nearshore portion of a beach profile is normally measured using a level and rod. This type of measure is very accurate. A fathometer is typically used to

measure the offshore depth while stationing is determined by electronic positioning equipment.

Prior to each survey, fathometers are calibrated by a method known as a bar check. Two plates are lowered to an exact distance below the fathometer transducer. The fathometer is then adjusted such that the distance measured by the unit equals the distance to these plates. Unfortunately, even with the most careful calibration techniques, some survey comparisons show a divergence at the offshore end of profile lines. From the depth of closure principal, we know that divergence should not occur.

Probably the most common type of offshore profile divergence can be attributed to a fathometer speed of sound error. This error is a function of water depth. Another profile divergence problem may be due to incorrect measurements of tide levels during a survey or data reduction in the office. This type of error, referred to as the tide and draft error, is a constant error independent of depth.

## CORRECTION METHOD

The divergence error at or seaward of the depth of the closure can be equated to a speed of sound constant multiplied by the water depth plus the tide and draft error (Fig. 1). This can be written in equation form as:

$$(d_2 - d_1) = Kd_1 + TD \qquad (1)$$

where, $d_1$ = water depth at a particular station during the old survey
$d_2$ = water depth at the same station during the new survey
$K$ = speed of sound error
$TD$ = tide and draft error

The divergence error further seaward is defined as:

$$(d_4 - d_3) = Kd_3 + TD \qquad (2)$$

where, $d_3$ = depth at the seaward end of the old survey
$d_4$ = depth at the seaward end of the new survey

Equation 1 can be solved for TD:

$$TD = (d_2 - d_1) - Kd_1 \qquad (3)$$

Equation 3 can then be substituted in equation 2 and solved for K:

$$K = \frac{(d_4 - d_3) - (d_2 - d_1)}{(d_3 - d_1)} \qquad (4)$$

The offshore portion of the old profile line can then be corrected with the following equation:

$$d_c = d + Kd = TD$$

where, $d_c$ = corrected depth of old survey
$d$ = uncorrected depth of old survey
$K$ = speed of sound error
$TD$ = tide and draft error

A series of tests were conducted to assess the validity of this method. Speed of sound and tide and draft errors were introduced into a series of beach profiles. For each type and combination of errors, the method was successfully able to determine the proper correction factor.

It should be noted that this method can be easily programmed on a computer. We have incorporated the method as an optional subroutine in our program which computes volumetric change;s between two surveys.

Should the situtation arise where the old survey appears correct and the newer one incorrect, the equations can easily be rewritten to accomodate this assumption.

Finally, this method should not be applied to profile line comparisons near inlets. Inlet currents have the potential to transport sand to depths beyond the depth of closure; thereby, invalidating the method at that location.

## CONCLUSION

A method was developed to correct the offshore portion of a beach profile comparison for closure. A correction factor is developed for the speed of sound error and the tide and draft error based on the divergence between profile lines beyond the depth of closure. An error was introduced into a series of profiles. The correction method was able to identify the errors both individually and in any combination.

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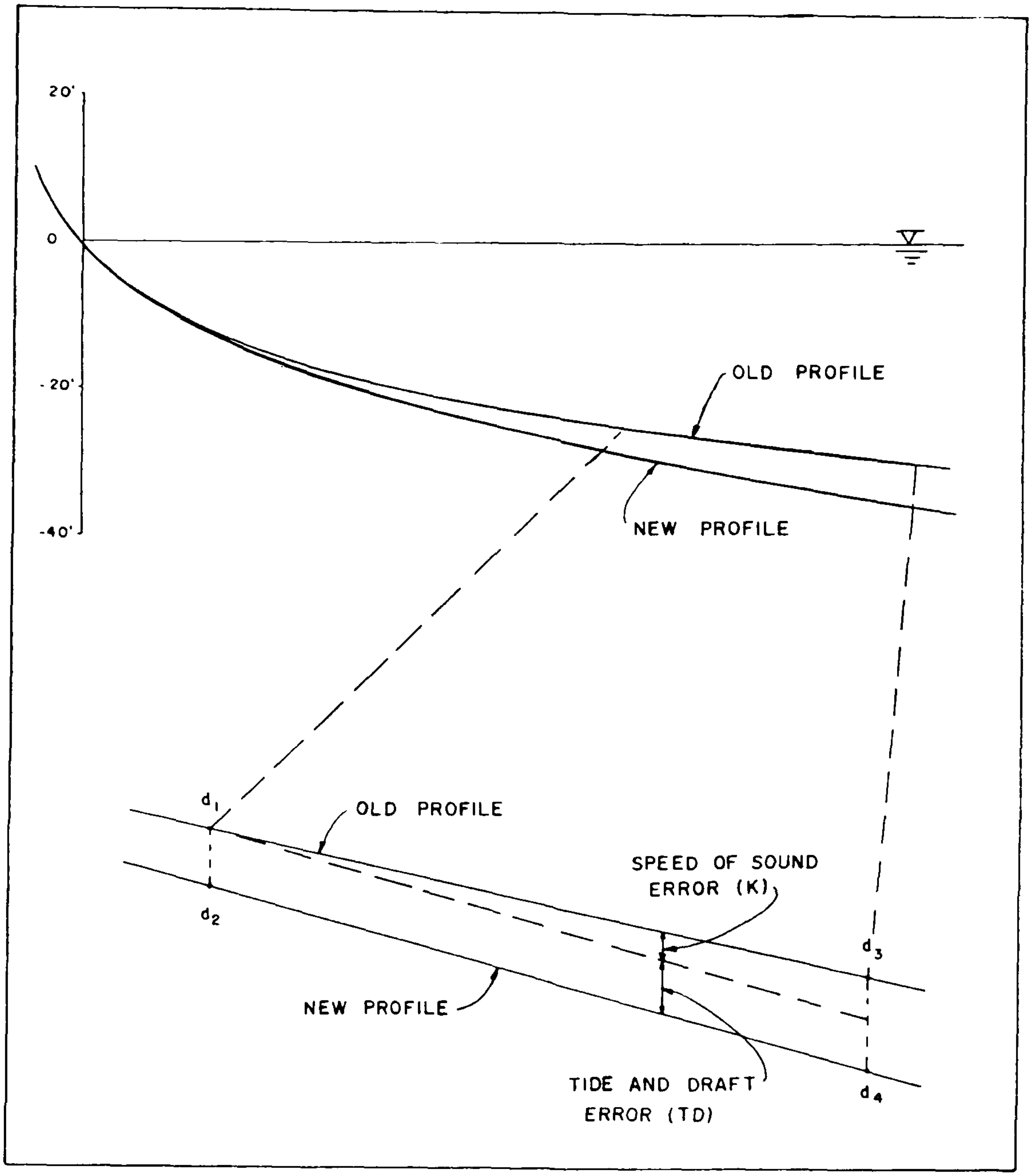


Fig. 1 DEFINITION SKETCH

# SESSION IV: TIDES

APPLICATION OF WATER LEVEL DATA TO SOUNDING REDUCERS

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## BIOGRAPHICAL SKETCHES

Joseph V. Mullin II is a graduate of Florida Institute of Technology where he received his degrees (A.S., B.S., B.O.T.) in Oceanography. Since graduation in 1973, he has been with the National Ocean Service, Office of Oceanography, Tides and Water Levels Branch. Mr Mullin has had extensive experience in all phases of project planning, data acquisition, processing, analysis, datum computation and application. He has served as Technical Advisor on Marine Boundary Field Parties in South Carolina and Florida, as Team Leader in the Tide Analysis Section and currently is coordinator of Hydrographic Activities in the Tides and Water Levels Branch.

## ABSTRACT

The main objective of a hydrographic survey is to precisely map the bottom features beneath the water surface using the most current information and techniques available with emphasis on safe navigation. The accuracy of nautical charts depends on the quality of the survey from which it was compiled. Soundings obtained during the course of a hydrographic survey must be corrected for the height of the water surface above or below the chart datum when the sounding was taken. The largest single corrector applied to soundings are tide reducers, which are verified hourly heights corrected to chart datum. The Tides and Water Level Branch, Office of Oceanography and Marine Assessment, National Ocean Service has the responsibility to plan tide and water level surveys, compute tidal datums and determine tidal zoning for all hydrographic and photogrammetric surveys performed by the National Ocean Service.

## INTRODUCTION

The National Ocean Service (NOS) operates a network of approximately 225 permanent tide and water level stations, located in stragetic locations throughout the Great Lakes and the Coastal and Estuarine Waters of the United States and the U.S. Trust Territories. The purpose of these stations, called the National Tide and Water Level Observation Network (NTWLON) is to provide continuous water level information over long periods of time. Some of the many uses of tide and water level data include nautical charting, tide predictions, Marine Boundary determination, monitoring sea level changes, storm surge and tsunami warning, court litigation and coastal research.

A typical NTWLON station consists of an ADR (Analog

Digital Recorder) tide gage, with a float and wire assembly inside a 12-inch diameter floatwell, a backup bubbler (pressure analog recorder) tide gage, and a tide staff or electric tape gage (ETG) inside a 4-inch floatwell, which is leveled to a network of 10 permanent benchmarks, with connections to National Geodetic Vertical Datum (NGVD) where possible. The tide station is manned by a contract tide observer who makes daily observations to verify station operation, and obtain staff/gage comparative readings. At many stations when a tide observation is taken, surface water temperature and density are also recorded. The information is collected monthly and mailed to NOS Headquarters in Rockville. A small number of tide stations are linked into the near real-time telemetry system which transmits tidal information through phone lines and during the coming year via satellite, directly to Headquarters in Rockville on a daily basis.

## PLANNING

The tidal requirements section of the project instructions originates in the Tides and Water Levels Branch (T&WLB). Included in these instructions are the requirements for numbers and location of tide gages, and length of operation. Tide station locations are selected based on an analysis of the tidal characteristics in the survey area.

Tidal requirements establish the standards and procedures necessary for field teams to maintain existing NTWLON stations, and to install, operate and remove short term subordinate tide stations installed for the hydrographic survey. The gage data provides observed tide reducers required for the reduction of soundings to chart datum. Correct and rapid handling of field requests for changes or clarification of tidal requirements helps to assure data quality and aids in the verification of the hydrographic survey. Historical tide sites are reoccupied and benchmarks releveled whenever possible, for the purpose of obtaining a datum recovery and updating tide predictions tables. Datum recoveries provide an additional level of confidence in the datums computed and are important in monitoring local sea level changes.

Preliminary tidal zoning based on predicted tides is provided and used by the hydrographic parties to apply preliminary tide corrections to soundings for a check of proper cross line closure and Hydrographic sheet (H-sheet) junction. Final tide reducers and zoning are based on observed tide data collected during the course of the hydrographic survey. Observed water level data is essential for including changes in the oceanic and meteorological environment which could be significantly different than the predicted tides. Tidal datums at the short term station are reduced to the equivalent of 19 year mean values through simultaneous comparison with a long term control station.

## FIELD INFORMATION

Upon completion of a hydrographic survey, tide data, benchmark and leveling information, and appropriate supporting documentation are forwarded to NOS Headquarters in Rockville for processing and analysis. Requests for final tide reducers and zoning are sent to Headquarters by Marine Centers, hydrographic field parties, or ships and are logged into the T&WL hydrographic data base. Hydrographic sheets and tide gage locations are plotted on nautical charts together with historical tide information in order to define the tidal characteristics of the survey area. Progress sketches supplied by the field units define the work limits of the survey area. Tide stations which are to be used in the final zoning scheme are indicated and readied for verification. Tide data and leveling information from new stations are verified to assure reliability and conformity to NOS standards.

## DATUM COMPUTATION

When the tidal data and benchmark information have been verified, a simultaneous comparison with the appropriate control station is performed to obtain the tidal datums at the subordinate tide station.

Generally the control station used would be the closest operational long term station. However the control station must reflect the same tidal characteristics and have similar response to meteorological changes as the subordinate station. In complex tidal areas such as Southern or Western Alaska or the Gulf of Mexico, selection of a proper control station is very important.

Parameters such as similarities in times, ranges, and diurnal inequalities are essential in selecting adequate control for datum determinations. When historical tide stations are reoccupied, a datum recovery can be accomplished through the leveling and bench mark information. This provides an opportunity to compare agreement between datums computed from the different data series as well as the tidal characteristics of range (Mn), mean time of high and low water intervals from Greenwich transits (HWI and LWI), and high and low water inequalities (DHQ and DLQ). Recent and historical tidal information are plotted onto the chart of the survey area as well as co-range and co-time lines to aid in determining a zoning scheme.

## FINAL ZONING

Final tide reducers used in sounding reduction must reflect the actual tide or water level stage as precisely as possible. When a tide station used for deriving tide reducers is required to cover an area over which there is significant differences in the time or height of the tide, adjustments must be made to the observed tide curve to correct for these differences. For adjustments of the tide reducers between tide stations it is necessary to divide the survey area into discrete zones.

Zoning essentially involves deciding which station data can be used for specific areas of the survey. Obviously one of the main constraints is the quality of data collected for the full period of the survey. Then, based upon present and historical data, the tide characteristics of the survey area can be defined. When the range of tide/or time of tide changes greatly, more zones are required for a sheet. Generally, a new zone should be established for every two tenths of a foot change in tide range or two tenths of an hour change in Greenwich intervals (times of high and low waters). This usually involves a linear interpolation of range and time between tide stations unless these differences can be attributed to changes in the hydrographic features of the area.

There are two types of zoning schemes presently in use. They are: (1) discrete zoning and (2) automatic zoning (also called multi-gage zoning). Discrete zoning is much more commonly used. In certain situations it is advantageous to use automatic zoning, however, its applications are much more restricted.

Discrete zoning involves dividing a sheet into portions or zones. Tides from a particular station will then be used as reducers for an entire zone. A sheet may contain only one zone or may be divided into several zones. Reducers for each zone are derived from data from one particular station. Reducers are computed from hourly height data by subtracting the value of the appropriate datum and then applying any necessary time and range corrections. A continuous set of reducers is computed by curve fitting techniques applied to the hourly height data. In automatic zoning reducers are computed for each position on the sheet by a weighted average of tides from two or more stations. The weight factor is inversely proportional to the distance from a given position to each of the tide gages. Thus the closer the soundings are to a particular tide station, the more weight the reducer from that tide station is given. The restrictions on using automatic zoning are that it cannot be used where a large difference in times of high and low waters exist or where there are pronounced changes in hydrographic features. In addition the sheet must be bounded by the tide stations. Automatic zoning is more commonly used in inshore bays and where boundary conditions are relatively uniform and where bracketed by tide gages. It is especially useful for zoning in areas where the range of tide is small and often masked by meteorological effects.

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# OPERATIONAL EXPERIENCE & INTERCOMPARISON of BUBBLER GAUGES AND PRESSURE TRANSDUCERS

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## BIOGRAPHICAL SKETCHES

John Oswald is presently the manager of Coastal Mapping at International Technology Limited. He is currently responsible for coordinating and implementing mapping projects in Alaska which are used primarily for marine boundary determinations. Prior to joining Itech he was a geodetic advisor and project manager with the National Geodetic Survey. He spent three years with the National Ocean Survey as a hydrographer. Mr. Oswald received the B.S. and M.S. degrees in Geodetic Science from the Ohio State University in 1970 and 1971 respectively.

Morgan Wolaver is presently a Project Manager/Staff Oceanographer at International Technology Limited. He is currently responsible for implementing precise navigation surveys, hydrographic projects and assisting in marine boundary surveys, including being Project Manager of a current tidal data acquisition contract. Prior to joining Itech he was a staff oceanographer for DMJM and an assistant hydrographer with Gardline Hydrographic Surveys. Mr. Wolaver received a B.S. in Oceanographic Technology from Florida Institute of Technology in 1978.

## ABSTRACT

International Technology Limited (Itech) has been involved in a number of surveying and mapping activities throughout the world requiring collection of tidal data. The past four years an extensive amount of tidal data has been collected in Alaska primarily to resolve coastal boundary problems related to oil and gas leasing. Inadequate tidal data exists in the high priority areas namely in ice covered waters. Pneumatic (bubbler) gauges have been the standard but are difficult to install and maintain in remote areas. Pressure type gauges have been operated in conjunction with the transducer type. The pressure gauges use a quartz sensor and are mounted on the seafloor. This paper presents operational experiences of both types and the numerical results of several recent

intercomparisons in the Bering Sea. A current site specific system to measure a years tidal record with several types of sensors with a telemetry system will be briefly discussed.

## INTRODUCTION

Long series tidal data (one year or more) for datum determinations was non existent in Alaska north of the Alaska peninsula and Aleutian Islands prior to 1980. The U.S. Department of Commerce, National Ocean Service (NOS formerly USC&GS) is the primary federal agency that operates a network of gauges along the coasts of the United States. The historic data in the seasonally ice covered areas is generally spans time periods of a few days to a few months. This data was collected by the USC&GS primarily in support of hydrographic operations. The need for accurate time series spanning at least one year has become very important since the discovery of an estimated 11 billion barrels of recoverable oil at Prudhoe Bay in 1968.

The State and Federal governments control all offshore deposits of minerals. Generally speaking the State has leasing rights to hydrocarbons (minerals) in the coastal zone within three nautical miles of the coast defined by the mean lower low water line on the best available chart. Normally this has been the latest edition of the nautical chart published by the NOS. An oil and gas lease sale in 1978 covered the offshore area adjacent to Prudhoe Bay. Although the lease sale was conducted, a sizable area was disputed because of a tiny gravel formation known as Dinkum Sands which had been mapped in the early 50's by NOS. The State and Federal governments have disputed the tracts and have gone to the Supreme Court to resolve the boundary question. As a result approximately 500 million dollars has been left in escrow depending upon the outcome of the Court's decision. Since this time the State of Alaska, Department of Natural Resources (DNR) has taken the initiative, in cooperation with the NOS and the Mineral Management Service to collect tidal data and prepare maps to be used for delineating, in a technically correct manner, the offshore boundaries. It is now in the best interests of all parties to collect adequate tidal data and agree on boundaries before the lease sales.

A one year time series was collected to resolve the Dinkum Sands project during 1980-81. Bubbler (pneumatic) and float well gauges were established at several sites. The data was collected at a cost of several million dollars and subsequently processed and analyzed by the NOS (Martin 1983, Stoney 1983). The current program of tide gauging is to establish one year records in the Bering and Chuckchi Seas by using a combination of gauges in a more cost effective manner. The lack of vertical piles or docks in the ice covered areas makes the use of float well gauges cost prohibitive.

Most of the areas where tidal observations are now needed in Alaska are ice covered during portions of the year. The ice thickness, movement, freezeup and breakup scenarios are highly variable depending on location. The nearshore zone along the Beaufort Sea cost (North Slope) normally freezes around the latter part of September and breaks up in late June/early July. Along the Norton Sound (Nome) area freezeup is not until early November and breakup in mid May. The potential thickness of the ice sheet, depth of water, and near shore ice dynamics are a major parameters affecting installation of gauges. Ice scours caused by collision of the keels of ice floes are an ever present problem particularly in the Chuckchi and Beaufort Seas. Any cables or tubing must be protected by burying in the sediments. Pressure transducers are ideally suited to this environment as they can be left deployed as stand-alone systems underneath the ice sheet.

## BUBBLER (PNEUMATIC) GAUGE OPERATION

Bubbler gauges have been in use for several decades. Since their inception modifications by government and private industry has produced a widely accepted tide gauge (Young 1977). Their usefullness stems from the ability to be set up in remote areas without docks or electrical power.

In principle bubbler gauges work by measuring the hydrostatic pressure from a fixed point in a body of water (Britton 1976). The hydrostatic pressure is defined in the absolute pressure equation $P = \rho gh + Pa$, where Pa is atmospheric pressure and $\rho gh$ is hydrostatic pressure, is the water density, g is the acceleration due to gravity at the location and h is the height of the water column above the sensing device. Pa falls out of the equation since it acts upon the recorder bellows opposing the same force at the sensing device. Gravity is constant and density is preset in the recorder. Changing the formula around $h=P/\rho g$. By measuring the change in pressure a direct proportional amount of water height can be recorded. This proportionality is about 0.5 psi to 1 foot of water. Note: Density is preset to 1.025 gm/cm3. The user should measure density as frequently as possible, especially in estuaries where fluxuations could create errors of 0.25 ft in 10 ft.

In operation of the sensing device, a short pipe, is anchored at some point in the water column. One end, called an orifice, is open, pointing downward and the other is coupled to a mechanical bellows and strip chart recorder via small diameter tubing. The recorder is connected to a source of gas which supplies a continuous flow to the pipe. A continuous flow of gas (normally dry nitrogen) provides a fixed point of water to gas interface at the orifice. As the water level changes, the pressure increases at the orifice changes which is sensed in the recorder by an expanding bellows. An ink pen, physically linked to the bellows, moves as the pressure changes charting the tidal signature on a strip chart. The strip chart is advanced at a fixed rate by a clock.

Advantages of these type of gauges are (1) no electrical power is required, (2) offshore structures are not necessary, (3) set up requires one person and can be accomplished in a couple hours, (4) wave induced error can be minimized with large diameter orifices (5) atmospheric pressure does not affect the data and (6) visual checks and results can be performed at any time.

Disadvantages are (1) bulkiness as compared to some other gauges (2) clock has to be wound every 5 days to maintain good accuracy, (3) sub freezing temperatures can affect the mechanics, (4) limited distance between the sensing device and recorder, (5) water density errors, (6) data must be digitized from analog records, (7) pressure leaks and, (8) tracking and timing problems on strip chart.

## PRESSURE TRANSDUCER GAUGE (PTG) OPERATIONS

Digital PTG sensors evolved about 10 years ago (Hayes 1978). PTG's have not really established themselves as well as other types of gauges in the hydrographic community. They are standard in deep sea research and oceanography. This possibility is from the lack of comparative testing and purchase cost. The variety of PTG's is large ranging from Bourdon tubes, strain gauges, bellows and crystal oscillators all coupled with digital data devices.

The principle of operation is based on measuring the hydrostatic pressure just as the bubbler gauge. They differ in that PTG's are small packages with no long tubes or gas supplies. Atmospheric pressure does not necessarily cancel out since most PTG's are set up to measure absolute pressure. Pressure is sensed at the transducer water interface and converted to a digital format which is then recorded on tape. Direct readout is possible and has been accomplished up to a mile away from the gauge via a seabed cable or a telemetry system mounted in a surface buoy.

PTG's are easily set up for operation. A small magnetic tape is installed in the tape transport and the internal clock initialized. The gauge is fixed to an anchoring structure to be set on the bottom or to a stable offshore structure. After project completion the gauge is retrieved by a diver, acoustic release or tethered buoy depending on how the user constructed the system. The data tape is read and displayed on a computerized device. Data is generally in frequency or pressure units requiring conversion to feet or meters.

Advantages are (1) simplicity of installation, (2) total instrumentation in one package, (3) minimal power requirements, (4) no mechanical adjustments, (5) no offshore structures required to set up, (6) no periodic servicing is necessary (7) wave induced errors are minimized mathematically, and (8) Data is in digital format. Disadvantages are (1) purchase cost may be much

higher than float well or bubbler gauges, (2) additional instrumentation and computation is required to obtain measurements in feet or meters, (3) atmospheric pressure data may be required, (4) water density errors, (5) retrieval hampered by bad weather, and, (5) integrity of data known only after retrieval.

## INTERCOMPARISON OF DATA

During the course of Itech's work several deployments have been made utilizing pressure transducers. These gauges (Sea Data) have been deployed to serve as back up to pneumatic (Metercraft) analog recorders. The results presented here are direct comparisons of pressure transducer data corrected for barometric pressure but not for density variations. Bubbler data was manually digitized whereas pressure data has been converted (initially) to a nine track tape which is read into Itech's in-house HP1000F computer system. A simple program was written which differences hourly heights of two different time series and computes a mean difference and the standard deviation (SDEV). Options exist to reject (or edit) observations greater than a set amount; normally 2 x SDEV.

The first comparison was made during April-May 1982 between two Sea Data gauges and a 0-10' Metercraft at Stebbins, Alaska. The sea surface was ice, about 4-1/2 feet thick.

The results of the simultaneous comparison are listed:

a) TDR 39 versus Bubbler (values in feet)
N=480 mean= 2.96 SDEV= +/- 0.080

b) TDR 41 versus Bubbler
N=484 mean = 3.92 SDEV = +/- 0.083

c) TDR 41 versus TDR 39
N = 485 mean = 0.96 SDEV = +/- 0.052

Another project at Kokechik Bay the data from a Sea Data (635-12) was compared to that of a 0-20' Metercraft series. Because of siting problems there was a 5 to 15 minute phase lag between the two gauges so only high and low water differences were computed:

a) 635 versus Bubbler 10/6/82 - 10/20/82
N = 53 HW/LW DIFF = 7.91 SDEV = +/- 0.09

b) 635 versus Bubbler 10/21/82 - 11/9/82
N = 61 HW/LW DIFF = 8.28 SDEV = +/- 0.09

c) 635 versus Bubbler 5/27/83 - 5/31/83
N = 17 HW/LW DIFF = 6.91 SDEV = +/- 0.09

In the first example at Stebbins the standard deviations are in the range of 0.05 to 0.08 foot. The stated accuracy of the 0-10 bubbler is +/- 0.1 foot. In the Kokechik Bay example the standard deviations are +/- 0.09 foot

compared to the +/- 0.2 accuracy stated for the 0-20′ bubbler. In both cases the pressure transducer data compares very favorably with the pneumatic gauge data set.

As part of the ongoing DNR program additional operational testing is being conducted at three remote sites in Alaska. Due to delays in operational software development the results of the intercomparison are not available. Four to five water levels sensors have been installed at each site. One location has a float operated system (ADR). The NOS is providing technical assistance to DNR regarding the data reduction.

## ELIM PROJECT

In August 1984 International Technology Limited was contracted by the DNR to set up and maintain at tide station in Elim, Alaska to establish one year record. This contract is one of three all in different areas and all utilizing slightly different tide gauge schemes. Elim is a small eskimo community about 500 miles northwest of Anchorage. Mobilization required a DC-6 aircraft to bring the 7000 pounds of equipment and pre-fab tide house from Anchorage to Elim. Equipment and tide house were trucked from the airstrip to the site. The Elim tide station incorporates three Metercraft bubbler gauges and two Sea Data 636-6M pressure transducer gauges. This number of gauges were set up for back up in case of failure or loss. Redundant data will provide checks on the stability and compatibility of two different types of gauges.

Two of the bubbler gauges are interfaced to Paros Quartz pressure sensors for direct digitization (Paros 1976). The digital data is sent into a Handar Model 540 data telemetry system. This data along with barometric pressure, battery voltage, air temperature and wind velocity/direction are stored for a three hour period then telemetered back to an office in Anchorage via a GOES satellite. Data is also stored on magnetic tapes inside of the Handar unit for back up.

Installation took seven days. A backhoe was utilized to dig and bury the three bubbler tubings out to the coast edge. Divers were then required to finish the burial another five hundred feet offshore. Unprotected tubing was weighted every fifty feet to prevent its floating to the surface and freezing into the winter ice layer. Orifices were clamped to a two foot pipe welded to a 3 by 3 foot half inch steel plate. A local boat was used to deploy the orifice. The tubing and orifices were set into the bottom sediments using a water jet. Both Sea Data gauges were rigged in a pre-built anchor with an attached acoustic beacon and deployed about one mile offshore in 30 feet of water. Position fixes were taken with a Motorola Mini Ranger III navigation system for future retrieval by a diver. A series of seven bench marks and tide staff were established to "preserve" the datum (Bodnar 1977).
Strip chart recorders, Handar unit and supplies are kept in the 7 x 7 x 7 foot insulated tide house. Electricity was wired to a charger for a bank of 12 volt batteries for the telemetry system and to run a heater to maintain 70 degrees

Farenheit. A constant 70 degree temperature is desired since several instruments were calibrated at this temperature and extreme cold temperatures have adverse affects upon the bubbler gauge strip chart recorder clocks.

A local resident was hired to check equipment and complete tide staff readings daily for comparison with the tide gauges. This insures the orifices have not moved or recorder induced errors have not entered unseen into the data. NOS uses a compilation of the staff to gauge comparisons and leveling results to establish the tidal elevations on the bench marks. After a weeks data is completed the reports are mailed to Anchorage and checked by the project manager.

Monthly trips are made by the project manager to Elim to run precise levels and perform maintenance on the equipment. Bubbler gauge mariograms and Handar data tapes are changed. The data is reviewed and a monthly operations and maintenance report is prepared. All raw data is forwarded to DNR for processing by the NOS and DNR personnel.

## SUMMARY

A description of the tidal datum program in Alaska is presented indicating a need for basic one year data sets in the western and northern part of the state. Because of the predominantly ice covered waters pneumatic and pressure transducer gauges have been utilized. Brief descriptions of each type of gauge are given with a listing of numerical results of simultaneous data from both types. A current project in Norton Sound is outlined which employs five separate sensors linked with a telemetry system. As can be seen from the results presented the pressure transducers although presenting some disadvantages offer an economical method to collect data in remote ice infested waters.

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SESSION V: HYDROGRAPHIC POSITIONING SYSTEMS AND DATA PROCESSING

# A PORTABLE ACOUSTIC NAVIGATION SYSTEM FOR HYDROGRAPHIC SURVEYS

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## BIOGRAPHICAL SKETCHES

Mr. Dave Porta is a Senior Applications Engineer and co-founder of Datasonics, Inc. in Cataumet, MA. He has been actively involved in the development and operation of underwater acoustic systems for more than 15 years. Mr. Porta is a member of MTS, AGU, the IEEE, and is a registered professional engineer in the state of Massachusetts.

Mr. Ervan G. Garrison is Lecturer and Associate Research Scientist in the Environmental Engineering Division, Department of Civil Engineering Division, Texas A&M University. He is 41 years old, married with two children. He has a Baccalaureate and Masters degree from the University of Arkansas and a Doctorate from the University of Missouri-Columbia. He has conducted research and published in international journals on topics ranging from archaeology to nuclear science. One of his prime interests at present is the application of high resolution survey techniques to the location of submerged historical resources.

## ABSTRACT

Datasonics has developed a low cost, local area navigation system which can be used for horizontal position control in a variety of offshore, river and lake surveys and engineering

applications. The system utilizes small, light weight underwater acoustic transponders which are deployed underwater. A ship board command unit with transducer is used to interrogate and measure range to the transponders, and a portable computer, plotter and data storage device can be used to provide real time position track guidance and position data storage capability. System Operation is analogous to operation of any range/range type of radio positioning system, except that underwater transponders are used in place of shore based radio transponders. Advantages of the system include low cost, long operating life, and the capability for use in areas where it would be inconvenient or costly to set up a shore based system. The entire system can be operated from a small skiff or "whaler" type of boat. A diver operated instrument has also been developed for use with the system which provides guidance to a diver for relocation of underwater objects. The unit provides a continuous display of both range and bearing for the diver to home in on. Transponders can be installed on moorings, instruments or other sea floor points which it may be necessary to have a diver relocate. In addition to a general system description, use of the system for performing a survey of a reservoir water intake route will be described. Dr. Ervan Garrison will present a review of system use by Texas A&M University in their coastal environmental monitoring program.

## SYSTEM DESCRIPTION

Radio frequency positioning systems are commonly used for horizontal position guidance in the performance of hydrographic surveys. These systems provide a ship position, in real time, based on acquisition of two or more ranges to RF transponders installed at known locations ashore. Systems using hyperbolic line of position generated by synchronized RF beacons, RF range/azimuth systems and other similar techniques have been selected for use depending on the particular application. These systems are generally capable of providing a position accuracy of better than 3 meters.

The primary disadvantage of these systems is the need for continuous shore based support, and high initial cost.

The acoustic system described herein is not presented as being competitive to a shore based system, but as a complimentary

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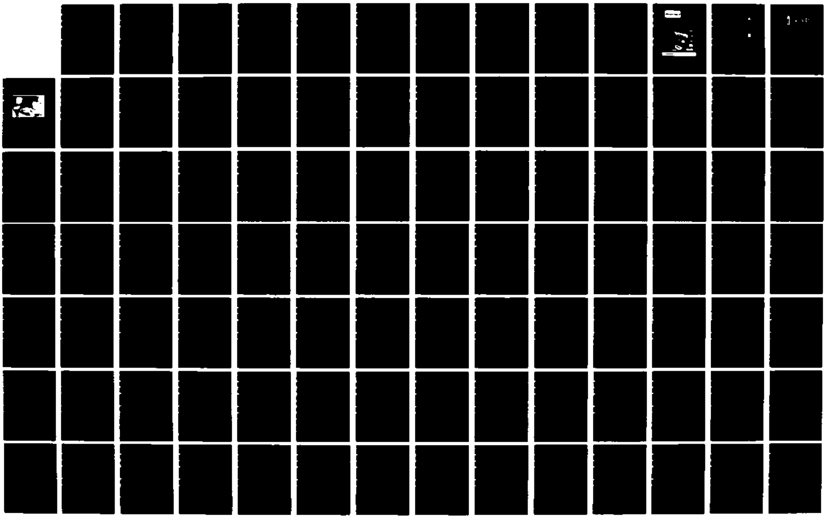

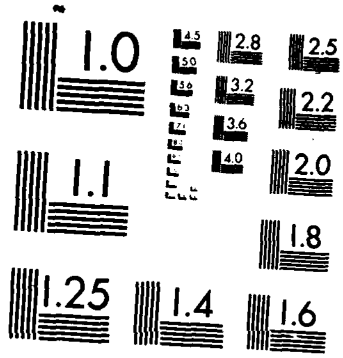


MICROCOPY RESOLUTION TEST CHART
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system which can be used as a stand alone positioning system in certain applications, or in many cases can be used in conjunction with a shore based system.

Advantages in using an acoustic system include the following:

1. Higher accuracy positioning capability within a relatively small survey area. (2 to 3 KM square)
2. Long maintenance free operating life. (2 years or more)
3. Ability to quickly mobilize aboard a small survey vessel.
4. Low cost.

The block diagram in figure 1 shows the major functional elements making up the acoustic navigation system. Figures 2, 3, 4 and 5 show the hardware items making up the system.

Basic operation is analogous to that of an RF range/range positioning system. Ranges are measured to two or more acoustic transponders deployed on the sea floor. Transponder depths are input via the keyboard during the initialization procedure. The processor converts the measured slant ranges to true horizontal ranges and determines an X-Y coordinate for each interrogation cycle. The survey vessel position can be updated at 5 to 10 second intervals and displayed on the processor CRT. The position information can be stored on floppy disk for post plotting, and printed out on the system data printer.

There are a few operational requirements which must be addressed when using an acoustic navigation system for hydrographic survey applications. The most important requirement in assuring a high degree of positioning accuracy, is implementation of an accurate calibration procedure.

Comparison With RF Shore Based Navigation Systems. An acoustic transponder navigation system operates in a manner analogous to a shore based range/range type of radio positioning system. Radio transmitting devices are placed at known locations and these well surveyed geographical locations are then used as a reference from which position information may be determined.

The Loran C navigation system uses this concept. Master and slave transmitting sites are set up at known locations. Hyperbolic lines of time difference between master and slave transmission can then be accurately plotted on a navigation chart.

Any ship which is equipped to receive the signals with a Loran receiver can then determine its latitude and longitude by reference to the received time differences between at least two pairs of stations.

Several commercial systems are available which utilize portable radio transponders which are set up at surveyed in shore sites. These stations are then used as a reference from which position information may be determined. The ship or object to be positioned is equipped with an active radio interrogator which sends a radio signal to the shore based transmitter/receiver sites. Each shore station receives the signal and transmits back at a discrete radio frequency. The round trip travel time is calculated by the ship processing equipment, and ranges to the shore station determined. With two or more ranges, a position can be determined by standard triangulation techniques.

The accuracy of such a system will depend on the geometry formed by the shore station and ship locations, by the number of reference stations used, and by the accuracy with which one knows the velocity of the electromagnetic transmissions. Sky wave abnormalities, ray bending, and other velocity errors will all contribute to some degree of position error.

The case for underwater positioning is complicated by several factors:

1. It is not generally feasible to easily place reference transponders or beacons at a well surveyed location on the sea bed.
2. Temporal and spacial variation in acoustic propagation velocity make precise range measurement over long distance quite difficult. Temperature gradients

occurring in the water column can cause ray bending which can produce "shadow zones" and other propagation abnormalities which can interfere with navigation capability.

3. The position determination becomes a 3-dimensional problem when one wants to accurately position a diver or other object moving between the water surface and sea bed.

In solving these problems, the focus is placed on the system calibration procedure.

For general purpose hydrographic surveys, we will concentrate on the shallow water case where come simplifying assumptions can be made. By "shallow" we mean water depths of perhaps 100 to 200 meters maximum depth.

Acoustic Transponder Array Relative Calibration. The most general scenario involves deployment of several transponders with no knowledge of transponder position on the sea bed, and with no surface nav system available. The transponder moorings can be deployed from a small boat, and are either lowered or free fall to the bottom.

As an example, let's assume a three transponder array is to be deployed.

The surface support vessel will be equipped with the following equipment:

A) Three transponders with suitable anchor clump weights, mooring lines and flotation elements.
B) Multi-channel interrogation module which monitors range to transponders, and a processor for the required calibration and navigation processing.
C) Temperature monitor or sound velocity measuring instrument with which to determine average propagation velocity.

The transponders are to be deployed in a rough triangular configuration.

The system operator or surveyor will have a base map which will have pre-plotted on it the desired transponder locations.

Once the transponders have been deployed the calibration procedure can take place. The most simple procedure involves a "baseline crossing" where the boat maneuvers across imaginary lines connecting the three transponder locations. The procedure is shown in Figure 6. As each baseline is crossed, the sum of ranges to the two transponders forming the baseline will pass through a minimum, yielding the baseline distance. The interrogator processor converts each measured slant range to true horizontal range. Once all three baselines are known, the geometry of the triangle can be easily calculated.

The processor can be used to establish a coordinate system, perhaps using transponder 1 as the origin, and baseline 1-2 as either the X or Y axis. This is shown in Figure 7 where transponder 1 location is assumed to be the origin and transponder location 2 to lie on the Y axis. With the three baselines known, the processor can now calculate the X, Y coordinates for all three transponders.

The surveyor, when performing general navigation routines, will want east and north coordinates, rather than X and Y coordinates so that he can easily correlate his position and heading with the heading indicator. This can be accomplished by an array "rotation" which is performed by the computer processor as the boat runs a course of constant heading while acquiring ranges to the transponders. The operator will input the heading from an external compass or gyro. The final rotated array is also shown in Figure 7.

Geodetic Calibration. The fore going section describes the relative calibration procedure which is necessary for any transponder navigation application where there is no real time radio positioning system available.

Most hydrographic surveys require absolute geodetic position

information. A radio positioning system such as Motorola Mini ranger, Trisponder or Cubic Autotape is normally used for the purpose of positioning the survey vessel.

In order to determine transponder geodetic coordinates, reference must be made to known geodetic positions, and acoustic ranges acquired to each sea floor transponder. This can be accomplished using the shore based positioning system. With surface position information from a shore based system as an input, software can be incorporated within the acoustic processor to tie down the transponder geodetic positions. With East/North coordinate information fed into the acoustic processor, acoustic ranges will be simultaneously acquired and transponder positions determined.

When a surface nav system is available, the transponder coordinates can be determined with respect to the surface nav coordinate system. The resulting acoustic "grid" will be coincident with that of the surface navigation system, and east/north coordinates will be the same regardless of which system is being used. In this case, there is no requirement for the baseline crossing, or "relative" transponder calibration. The transpnders can be easily "surveyed in" with respect to known surface position using the radio nav system.

Some applications may not require the shore based radio nav system for transponder calibration. For instance, a local area hydrographic survey may be desired in a harbor where piers or other structures of known position are available. Transponders could then be attached to these points and then utilized as position references. If two points along the shoreline are of known position, the transponder locations could be surveyed in by theodolite or a range/azimuth technique as the vessel personnel lower the transponder to the bottom.

Once calibrated, the transponder array can be left deployed for periods up to 2 years or even longer with the use of lithium batteries.

Navigation along preprogrammed track lines using the acoustic system can proceed exactly as when using a surface based

navigation system. The vessel position can be plotted in real time, and both position and depth data stored for later post processing.

In summarizing the use of an acoustic system for local hydrographic surveys, it is important to remember that this type of system will not replace the requirement for the longer range radio navigation system. When used in conjunction with such a system, however; the acoustic system offers a very low cost, portable operating system for local area surveys which can be left in place for long periods of time. Depending on the location and particular requirements of a survey area, the acoustic system may be able to be deployed and calibrated without use of a shore based system.

It should be noted that Datasonics produces acoustic hardware necessary in using this method of navigation. The shipboard acoustic command unit has an RS-232 serial output, or GPIO parallel output for input to a processor. The company is currently producing software which will be available for either the HP200 series computers, or the IBM PC. Datasonics engineering personnel are also available to assist users who wish to develop their own software for use in acoustic navigation.

Example Use of Acoustic Navigation For Hydrographic Survey. The Datasonics Aquarange System was recently used for performing a hydrographic and sub-bottom profiling survey for the Portland, Maine Water District. Datasonics operated the acoustic equipment under a sub contract to Camp, Dresser & McKee, Inc., a Boston A&E firm.

Figures 8 and 9 show the Sebago Lake reservoir general area and a base map of the area to be surveyed. Two water intake lines extend out into the lake to locations at approximately 50 feet in depth. The water district, in evaluating techniques to improve overall water quality, is considering extending these lines outward to a depth of 80 to 85 feet where the water quality will be improved.

The Aquarange System was used for horizontal positioning while

the Datasonics Model SBP-5000 dual channel acoustic profiling system was used for both bathymetric and sub-bottom profiling data acquisition.

The locations of the two water intake lines were known from previous surveys, and are shown on the map in Figure 9. Two transponders were installed at the ends of the intake lines, and 2 additional transponders were deployed at locations just outside the survey area. With a known baseline (between the two intake lines), ranges were acquired at several locations to all four transponders, and the last 2 were quickly surveyed in.

A 16 foot Boston Whaler was used to perform the survey. A small Honda generator provided 110 VAC power to the Datasonics acoustic command unit, dual channel profiling transceiver and graphic recorder installed in the boat. Two operators performed the survey, with one man to operate the boat, and a second man to operate the equipment. The acoustic interrogation transducer, installed in a small depressor vehicle was deployed off the bow at a depth of 5 feet. A computer processor was not available, nor for that matter, was the boat equipped with a compass. Track lines were run using visual sighting with periodic triangulation checks performed manually as each line progressed.

We arrived at the job site at 10:00 a.m. on a Monday morning. The transponders were deployed, calibrated, and the equipment installed in the Whaler by mid afternoon. The survey data acquisition was complete by the end of the following day, with work limited to daytime hours.

Figure 10 shows the post plotted track lines with fix numbers and water depths relative to the current lake level datum. Figure 11 shows the contour chart prepared from the hydrographic data.

This type of survey job represents a good application for the use of acoustics, where it is desirable to minimize cost, mobilization time, and where the survey is suitable for acoustic ranging using 3 or 4 transponders. It is an example of a survey requirement which can be met without need for

mobilizing a shore based positioning system.

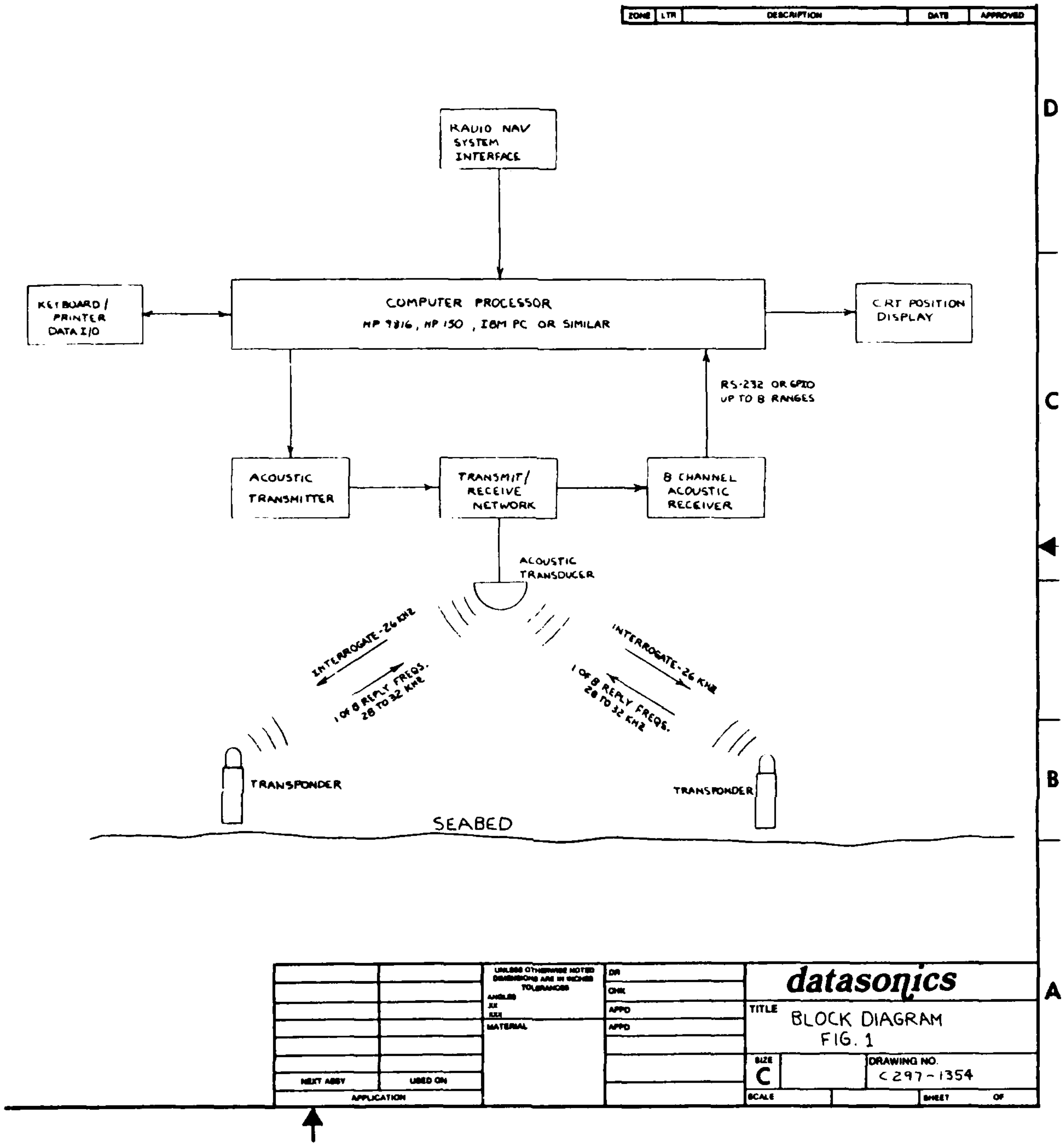
Example Use of Aquarange Acoustic Components for Sub Sea Ranging and Relocation. The Aquarange series of acoustic ranging components can also be used for a variety of applications other than the navigation requirement discussed above. This would include sub surface positioning of hardware items, marking of underwater positions which must be relocated, and the recovery of underwater instrumented moorings.

Erv Garrison and Frank Kelly in the Department of Civil Engineering at Texas A&M have been setting out instrumented moorings in areas of extremely low visibility in the Gulf of Mexico. Several moorings have been lost in the past due to fishing or other activities which result in surface floats missing and moorings being dragged from location. Datasonics Model UAT-377 transponders are now installed on these moorings and have proved to be very effective in the recovery of these moorings.

A standard Model ACU-297 portable acoustic ranging unit is used to get fairly close (within a few hundred meters) to the transponder attached to the mooring. A diver then proceeds to swim, using the Model DRI-267 diver held locator, directly to the sea floor transponder. The unit provides a digital range readout, and an analog bearing display, both of which are lighted for use in operation under conditions of extremely low visibility.

Conclusions. Although the acoustic technique has not been extensively used for horizontal positioning in performance of hydrographic surveys, it would seem to be a very economical alternative to shore based radio systems in certain circumstances. The low cost, small component size, and portability will make the system useful for local area surveys where it is not practical from an economic or security standpoint to maintain a shore based system over an extended time period. The low component cost will also reduce the risk associated with use of valuable instrumentatin aboard small survey vessels operating in remote areas.

The acoustic components can also be utilized in a range of other underwater relocation and ranging applications. Acoustic ranging components are available for operation by either shipboard personnel or by divers.



RADIO NAV SYSTEM INTERFACE
KEYBOARD / PRINTER DATA I/O
COMPUTER PROCESSOR
HP 9816, HP 150, IBM PC OR SIMILAR
CRT POSITION DISPLAY
RS-232 OR GPIO
UP TO 8 RANGES
ACOUSTIC TRANSMITTER
TRANSMIT/ RECEIVE NETWORK
8 CHANNEL ACOUSTIC RECEIVER
ACOUSTIC TRANSDUCER
INTERROGATE-26 KHZ
1 OF 8 REPLY FREQS. 28 TO 32 KHZ
INTERROGATE-26 KHZ
1 OF 8 REPLY FREQS. 28 TO 32 KHZ
TRANSPONDER
TRANSPONDER
SEABED
datasonics
TITLE BLOCK DIAGRAM FIG. 1
SIZE C
DRAWING NO. C297-1354

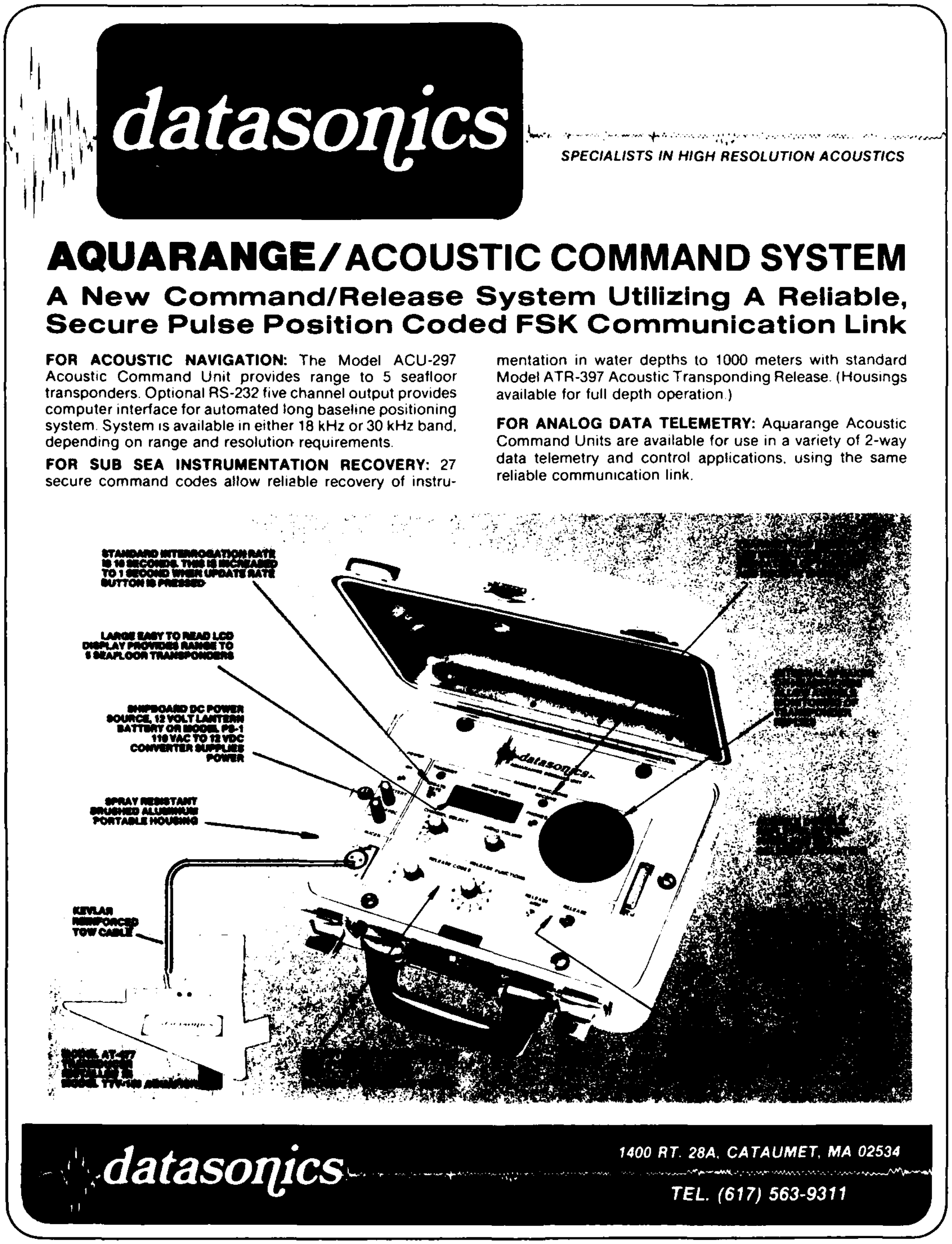
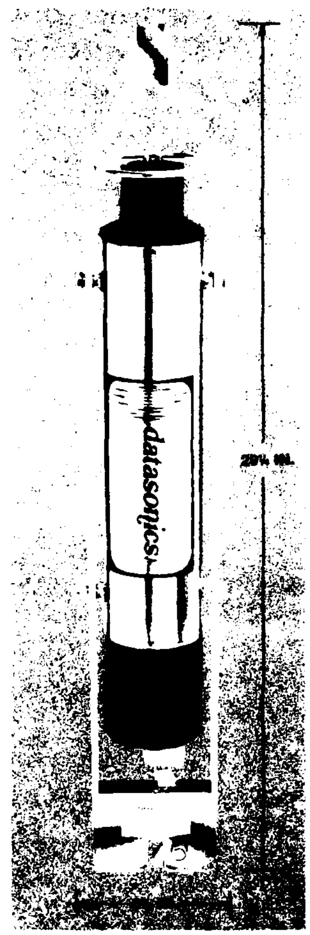

datasonics
SPECIALISTS IN HIGH RESOLUTION ACOUSTICS
AQUARANGE/ACOUSTIC COMMAND SYSTEM
A New Command/Release System Utilizing A Reliable, Secure Pulse Position Coded FSK Communication Link
FOR ACOUSTIC NAVIGATION: The Model ACU-297 Acoustic Command Unit provides range to 5 seafloor transponders. Optional RS-232 five channel output provides computer interface for automated long baseline positioning system. System is available in either 18 kHz or 30 kHz band, depending on range and resolution requirements.
FOR SUB SEA INSTRUMENTATION RECOVERY: 27 secure command codes allow reliable recovery of instrumentation in water depths to 1000 meters with standard Model ATR-397 Acoustic Transponding Release. (Housings available for full depth operation.)
FOR ANALOG DATA TELEMETRY: Aquarange Acoustic Command Units are available for use in a variety of 2-way data telemetry and control applications, using the same reliable communication link.
STANDARD INTERROGATION RATE IS 10 SECONDS. THIS IS INCREASED TO 1 SECOND WHEN UPDATE RATE BUTTON IS PRESSED
LARGE EASY TO READ LCD DISPLAY PROVIDES RANGE TO 5 SEAFLOOR TRANSPONDERS
SHIPBOARD DC POWER SOURCE, 12 VOLT LANTERN BATTERY OR MODEL PS-1 110 VAC TO 12 VDC CONVERTER SUPPLIES POWER
SPRAY RESISTANT BRUSHED ALUMINUM PORTABLE HOUSING
KEVLAR REINFORCED TOW CABLE
datasonics
1400 RT. 28A, CATAUMET, MA 02534
TEL. (617) 563-9311

Figure 2

# MODEL ATR-397

## ACOUSTIC TRANSPONDING RELEASE




### DESCRIPTION

The ATR-397 is a rugged, reliable releasing transponder designed for deployment in water depths to 1000 meters. The transponder housing and frame are constructed of Type 316, corrosion resistant stainless steel.

Standard replacable alkaline batteries provide long operating life in excess of one year and 50,000 range replies.

The spring loaded rachet/pawl release assembly is housed in a pressure compensated oil filled chamber, providing a minimum amount of bearing stress from operation under deep water pressure.

### FEATURES

- Immersion turn on electrodes provide turn on in fresh or salt water with no pressure housing penetration.
- Rugged stainless steel frame provides release load capability of 2,000 lbs. (Heavier duty frames available.)
- Recockable release mechanism can be cocked by hand. The mechanism is protected by rugged slide plates to assure positive release action.
- Internal switch settings provide selection of 5 reply frequencies and 27 unique command codes.
- Separate transmit, receive, and release batteries provide maximum protection from failure and highest recovery assurance.
- Transponder can be fitted with optional rope cannister to allow use as a "pop-up buoy".
- Units available in 18 kHz or 30 kHz frequency range, depending on range and resolution requirements.

### APPLICATIONS

Long baseline acoustic navigation, ranging, sub sea instrumentation recovery device.

Recoverable position marker

Pop-up buoy marker

Recoverable data telemetry transponder

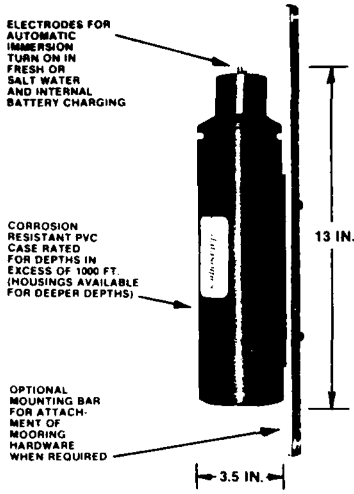
### SPECIFICATIONS

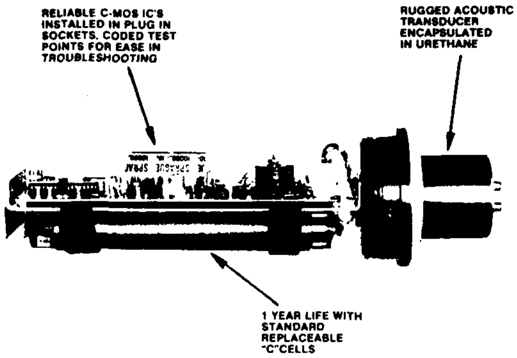
| | | | |
|---|---|---|---|
| **RANGE INTERROGATE FREQUENCY*:** | 26 kHz | **OPERATING DEPTH:** | 1000 meters standard (full depth housings available) |
| **REPLY FREQUENCIES*:** | Internally selectable, 28, 29, 30, 31 or 32 kHz | **TURN ON:** | Immersion turn on |
| **PULSE LENGTH:** | 5 msec | **RELEASE COMMAND:** | Pulse position coded FSK |
| **TURN AROUND TIME:** | 20 msec | **NUMBER OF CODES AVAILABLE:** | 27 codes, internally set |
| **STABILITY:** | ±0.1 msec | | |
| **INHIBIT TIME:** | 0.8 second | **RELEASE TYPE:** | Solenoid actuated spring loaded rachet pawl assembly<br>Externally recockable by hand |
| **SOURCE LEVEL:** | +188 db ref. 1 μPa @ 1 meter | | |
| **OPERATING LIFE:** | 12 months, 50,000 replies | | |
| **BATTERY POWER:** | Receiver - 6 "C" size alkaline cells<br>Transmitter<br>1 - 12.5V smoke alarm type battery<br>Release solenoid<br>4 - 9V transistor type batteries | **RELEASE LOAD CAPABILITY:** | 2000 lb. standard |
| | | **WEIGHT:** | In air - 25 lbs<br>In water - 12 lbs |

*Units available in 18 kHz frequency range. Selection based on range and resolution requirements.

NO. 1006

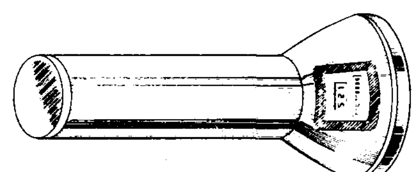
Figure 3




**MODEL UAT-377 UNDERWATER ACOUSTIC TRANSPONDER**

Lightweight diver held interrogator unit provides display of range and bearing direction to selected sub sea transponder. Dual readout of range and signal amplitude allows relocation of transponder under conditions of zero visibility.



**MODEL DRI-267 DIVER OPERATED, INTERROGATOR**

## AQUARANGE COMPONENT SPECIFICATIONS

### MODEL ART-277 ACOUSTIC RANGING TRANSCEIVER

| | |
|---|---|
| INTERROGATE FREQUENCY | [illegible] |
| REPLY FREQUENCIES | [illegible] |
| TRANSDUCER TYPE | [illegible] |
| TRANSDUCER MOUNTING | [illegible] |
| POWER OUTPUT | [illegible] |
| RANGE | [illegible] |
| REPETITION RATE | [illegible] |
| VOLUME CONTROL | [illegible] |
| RANGE DISPLAY | [illegible] |
| POWER REQUIRED | [illegible] |
| DIMENSIONS | [illegible] |
| WEIGHT | [illegible] |

### MODEL UAT-377 UNDERWATER ACOUSTIC TRANSPONDER

| | |
|---|---|
| INTERROGATE FREQUENCY | [illegible] |
| REPLY FREQUENCY | [illegible] |
| POWER OUTPUT | [illegible] |
| OPERATING LIFE | [illegible] |
| BATTERY PACK: | 8 Customer Replaceable Alkaline or Rechargeable C Cells |
| OPERATING DEPTH: | 1000 Feet Standard. Housings For Increased Depth Available |
| TURN ON: | Immersion Turn On Electrodes Provide Automatic Turn On and Provision For Internal Battery Charging |
| HOUSING: | Corrosion Proof PVC |
| DIMENSIONS: | 3.5 Inch OD x 13 Inch Tall |
| WEIGHT: | In Air 5 lb In Water 0.5 lb |

### MODEL DRI-267 DIVER OPERATED RANGE INTERROGATOR

| | |
|---|---|
| INTERROGATE FREQUENCY: | 26 kHz |
| REPLY FREQUENCIES: | Selectable 28, 29, 30, 31, 32 kHz |
| POWER OUTPUT: | 10 Watts |
| RANGE: | To 500 Meters |
| REPETITION RATE: | 1 pps |
| DISPLAY: | LED Digital Range Display<br>Analog Bearing Display |
| OPERATING LIFE: | 24 Hours Between Charges |
| BATTERY TYPE: | Rechargeable Cells |
| DIMENSIONS: | 3 Inch OD x 8 Inch [illegible] |
| WEIGHT | In Air 5 lb<br>In Water Slightly Positive Buoyancy |

NO 1001

Figure 4

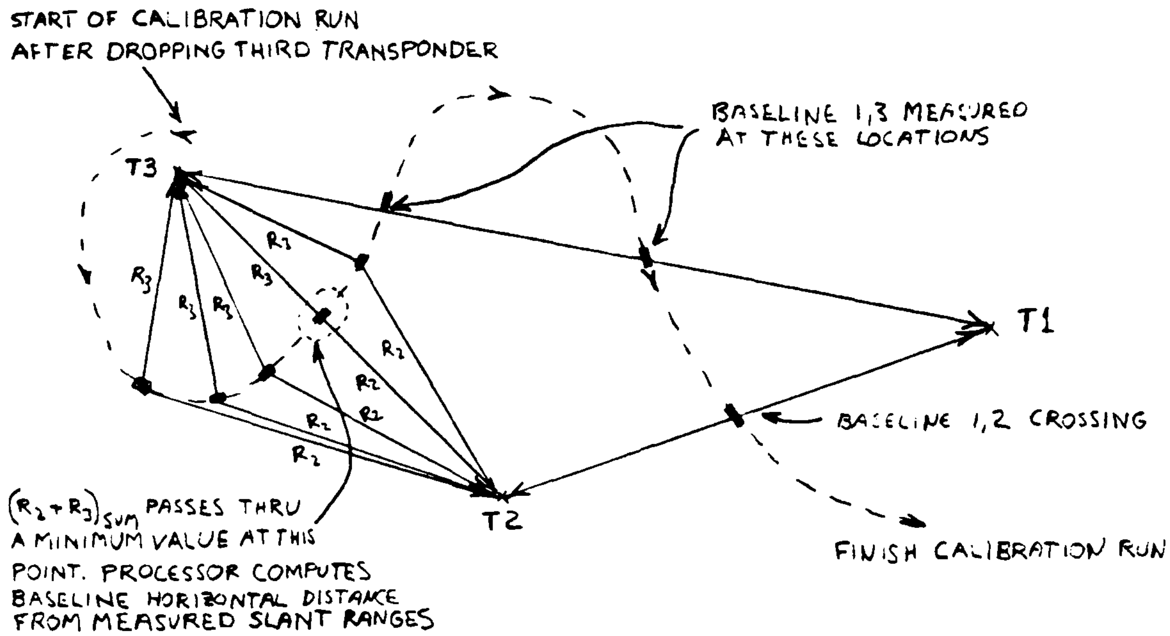
## The Model 16 is small enough to sit on your desk. It only *acts* like a big computer.

With the Series 200 Model 16 Personal Technical Computer, Hewlett-Packard again brings big technology down to size — in a 16-bit computer that's not much bigger than your office telephone. But it needs a *lot* of room in your thinking — it's based on the powerful MC68000 microprocessor from Motorola, *the* state-of-the-art in 16-bit computing today. With 32-bit internal architecture and 8 MHz clock rate, the 68000 is fast and powerful enough to meet those demanding technical and scientific applications you deal with. The power is there.

But powerful processing isn't everything ...memory, languages and graphics are equally important. The Model 16 is available with BASIC, HPL, or Pascal. Memory, starting at 128K, reaches to a full 768K bytes for large programs and data; with direct memory access (DMA), that data can be transferred at up to 750K words second. And a 9-inch CRT with 300 x 400 graphics resolution lets you turn that data into interesting and meaningful displays. Five soft keys (ten with shift) allow you to interact easily, while the "twivel" (tilt and swivel) option makes for easy and comfortable use. An exclusive rotary control knob allows you to scroll through programs quickly or "experiment" with input while watching on the screen. The system capacity is there.

Finally, its "synergy" and common architecture with previous models bring you the Model 16 at a remarkable cost. The power is there. The system is there. And so is the affordability.

Figure 5



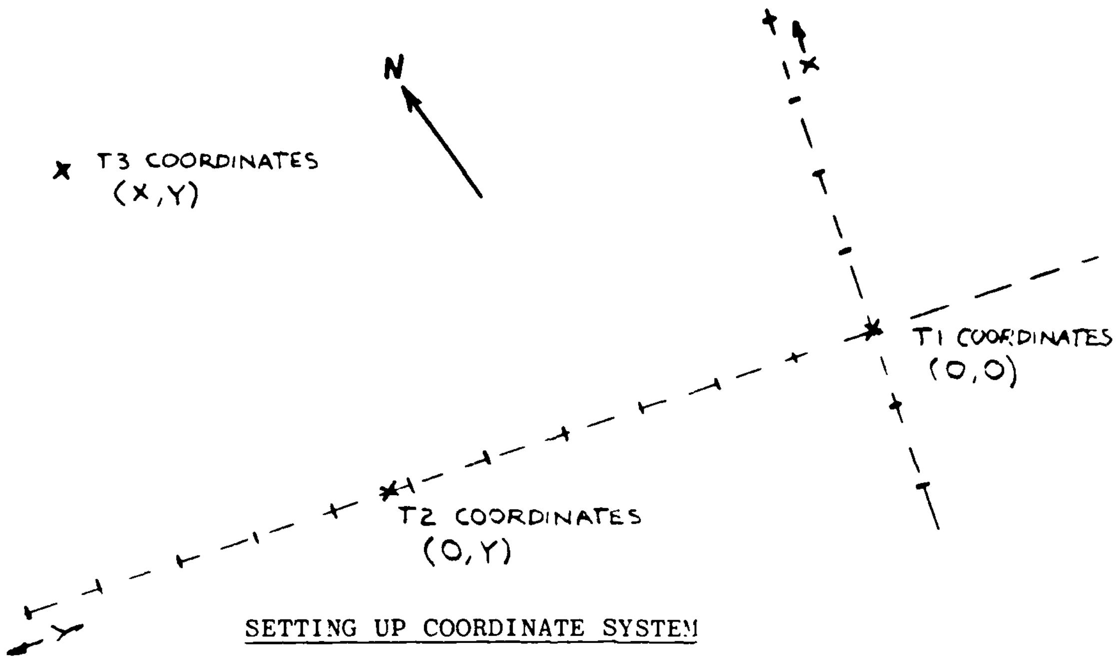

BASELINE 1,2 = $(R_1+R_2)_{MINIMUM}$

BASELINE 1,3 = $(R_1+R_3)_{MINIMUM}$

BASELINE 2,3 = $(R_2+R_3)_{MINIMUM}$

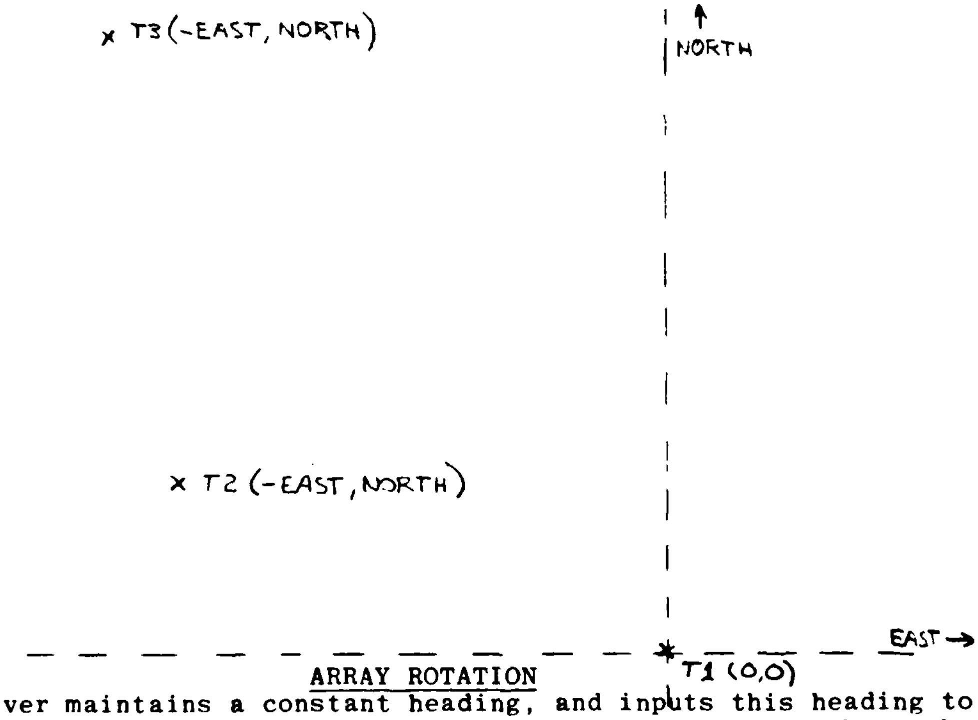
Baseline Crossing Calibration
Procedure

Figure 6




SETTING UP COORDINATE SYSTEM

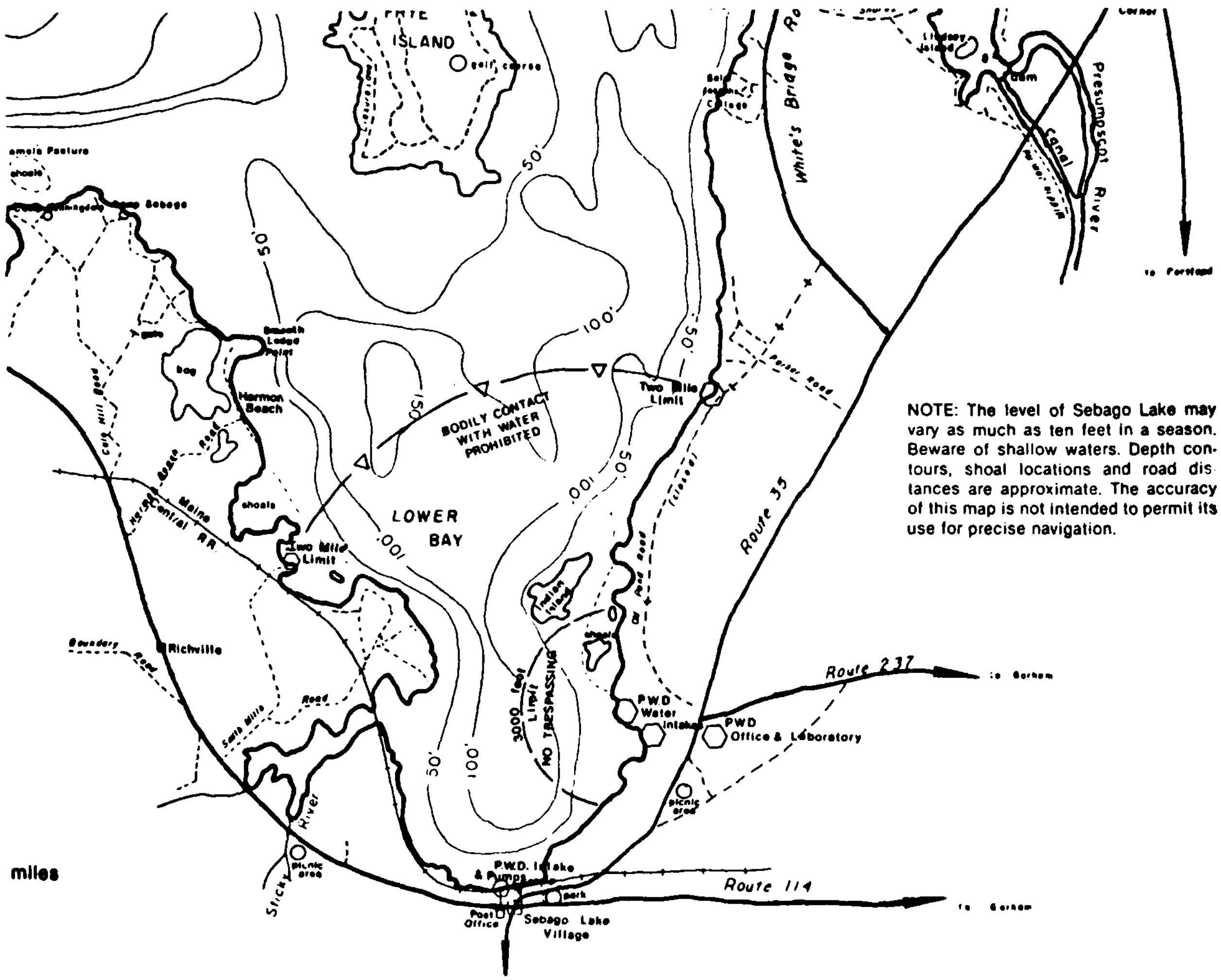
Calibration program defines origin of coordinate system at location of transponder No. 1 and places transponder No. 2 on the Y-Axis. With 3 sides of the triangle measured in the baseline crossing program, or measured directly using a "smart" transponder, the geometry of triangle 1, 2, 3 is defined.




ARRAY ROTATION

The diver maintains a constant heading, and inputs this heading to the processor. The software program "rotates" the array about the origin to allow output of position coordinates in East, North distances relative to the transponder No. 1 origin. Processor can now compute heading information to correlate with diver's magnetic compass.

Figure 7



ISLAND
LOWER
BAY
BODILY CONTACT
WITH WATER
PROHIBITED
Two Mile
Limit
3000 feet
Limit
NO TRESPASSING
Harmon
Beach
Richville
Maine
Central RR
Sticky River
P.W.D.
Water
Intake
PWD
Office & Laboratory
P.W.D. Intake
& Pumps
Post
Office
Sebago Lake
Village
Route 35
Route 237
Route 114
White's Bridge
Presumpscot River
Canal
dam
miles
NOTE: The level of Sebago Lake may vary as much as ten feet in a season. Beware of shallow waters. Depth contours, shoal locations and road distances are approximate. The accuracy of this map is not intended to permit its use for precise navigation.


Figure 8

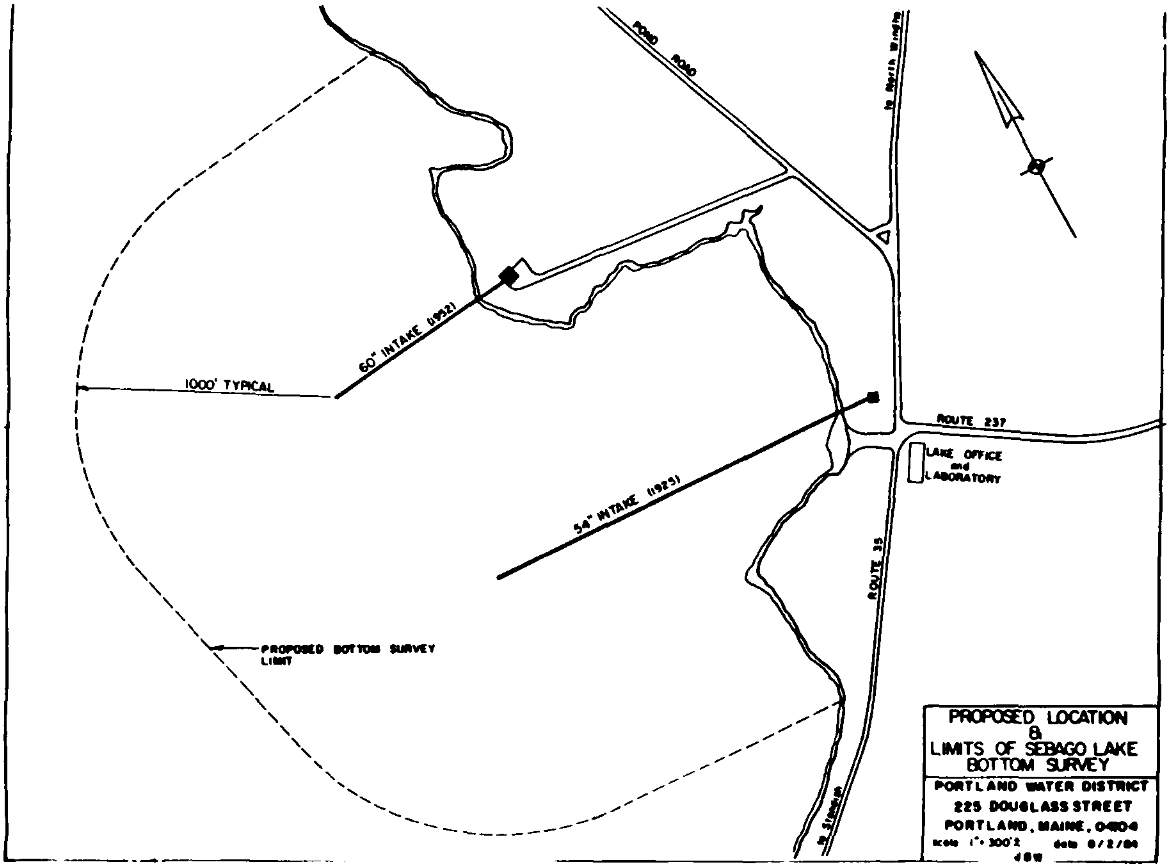
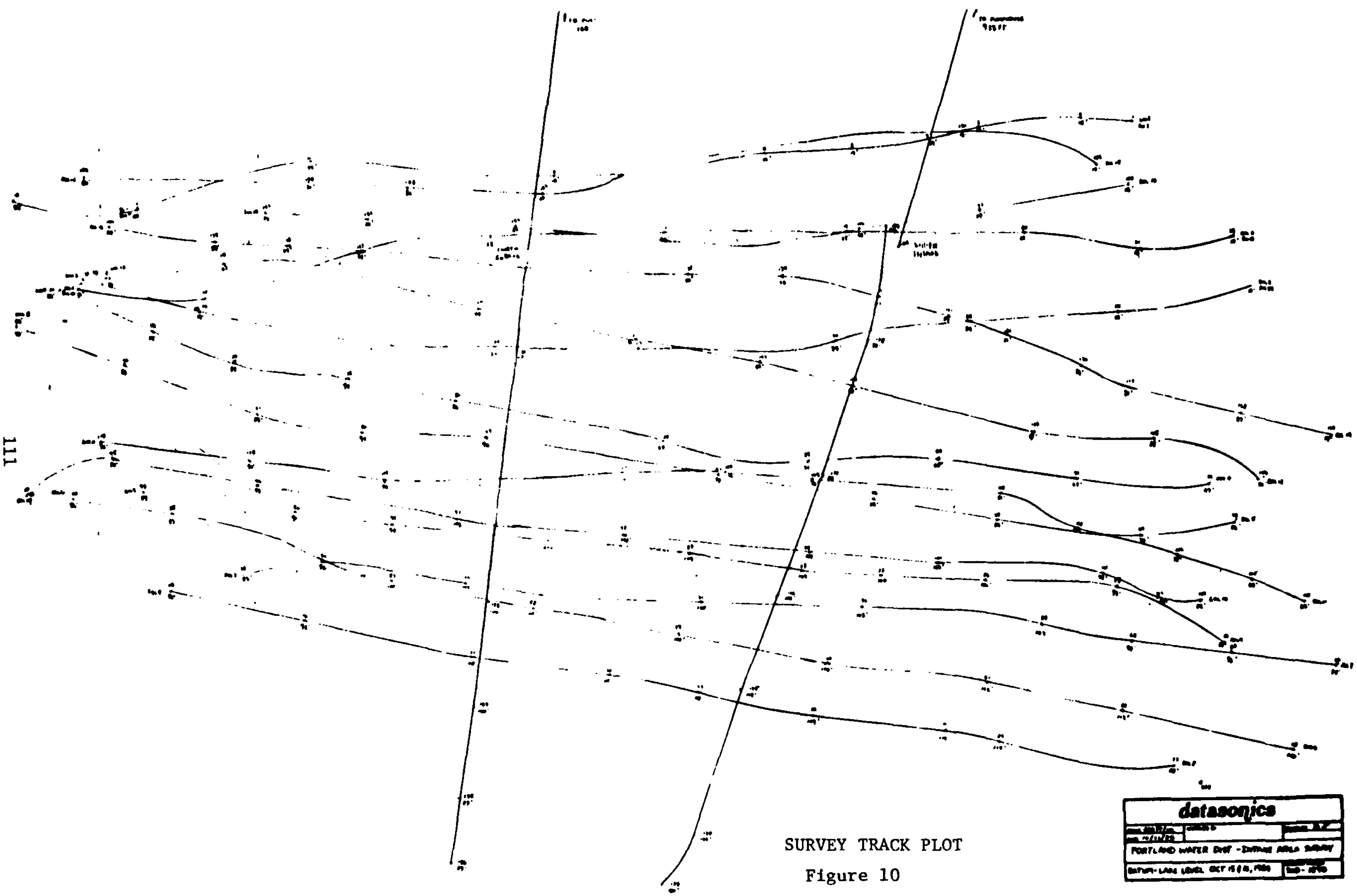
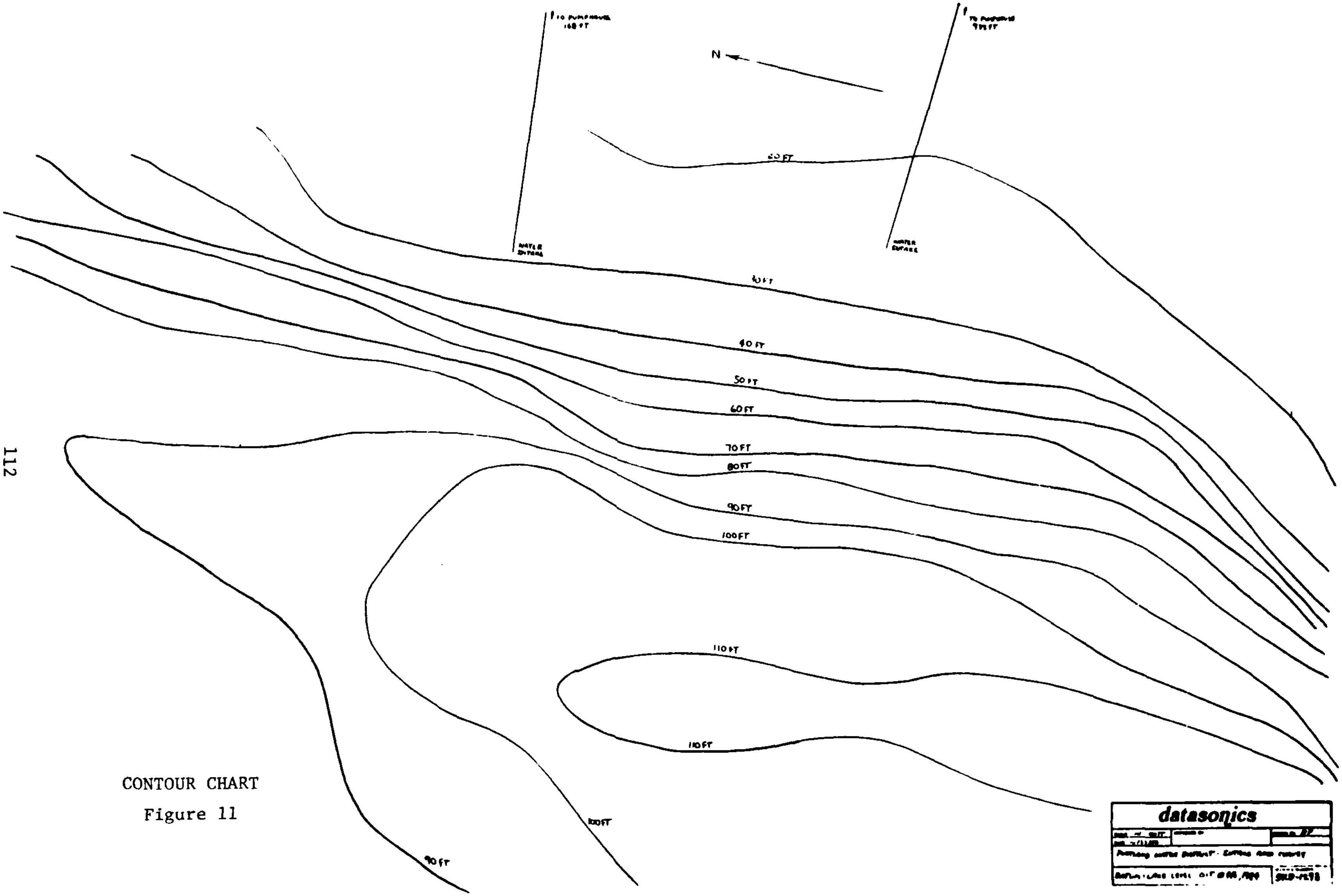

POND ROAD
to North Windham
60" INTAKE (1952)
1000' TYPICAL
ROUTE 237
LAKE OFFICE
and
LABORATORY
54" INTAKE (1925)
ROUTE 35
PROPOSED BOTTOM SURVEY
LIMIT
PROPOSED LOCATION
&
LIMITS OF SEBAGO LAKE
BOTTOM SURVEY
PORTLAND WATER DISTRICT
225 DOUGLASS STREET
PORTLAND, MAINE, 04104

Figure 9




SURVEY TRACK PLOT

Figure 10




CONTOUR CHART

Figure 11

# NAVIGATION SOFTWARE WITH ON-LINE QUALITY CONTROL FOR SMALL VESSEL OPERATIONS

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Systems Programmer
International Technology Limited
9000 Clay Road Suite 110
Houston, Texas 77080

Kevin C. Keener
Systems Engineer
International Technology Limited
3127 Commercial Drive
Anchorage, Alaska 99501

## BIOGRAPHICAL SKETCHES

Timothy Hoelzle is presently the Systems Program Manager at International Technology Limited. He is responsible for program development of all real time data acquisition and various post-processing software currently being utilized by Itech. This encompasses navigation as well as inertial-laser digital terrain data acquisition. Prior to joining Itech he was office manager and programmer for several civil engineering and land surveying firms located in the State of Florida. Mr. Hoelzle studied land surveying at Pinellas Vocational Technical Institute, Clearwater Florida in 1971.

Kevin Keener is presently the Systems Engineer for International Technology Limited's hydrographic department. This responsibility extends to the development and testing of hydrographic equipment for operations in the field. Prior to employment with Itech he was chief navigator and electronic technician for Western Geophysical. Mr. Keener studied electrical engineering and surveying at the University of Alaska. He graduated from Washington Technical Institute, Seattle, Washington, in 1978 and currently holds an FCC first class license.

## ABSTRACT

Modern computer technology allows the hydrographic surveyor to design a navigation/data collection program tailored to his specific requirements. Navigational computations with quality control features, data storage and steering indication are now possible in a single, small, highly portable data processor. The memory size, peripheral control, and microprocessor speed of these units also allows the operation of peripheral equipment when not restricted by vessel size and environmental conditions. This paper describes the capabilities and operation of such a system developed by International Technology Limited.

## INTRODUCTION

With the technology available today for use by field engineers, data acquisition has become increasingly more complex while utilization of this equipment has become considerably simplified.

This has resulted from the improvement of data processors and small computers. The complexity comes from numerous data acquisition units and peripherals that are readily available, operational ease comes from highly developed user friendly software. This situation has placed most of the burden on the system programmers and engineers to stay abreast of the industry's technological growth patterns and to simultaneously utilize this growth to provide better data acquisition systems.

## COMPUTER AND PERIPHERAL HARDWARE CONSIDERATIONS

The overall performance of any automated hydrographic system will be greatly affected by the choice of data processor or computers used. In choosing a computer, several important capabilities that should be considered are; computer power requirements, memory capacities, cpu capabilities, and the type of operating system (software-firmware).

At Itech, some of our primary objectives were to have high portability, and sufficient versatility to be usable for several years. These objectives show the importance of the above mentioned considerations. To achieve these objectives our computer had to have low power consumption and be light-weight for portability. Have flexibility to control peripherals easily, so that several data acqisition units and data loggers can be used simultaneously. Coupled with high speed processor execution times and a high level operating system allows the capacity for extremely fast data monitoring and logging systems. At the time of this decision, we found that the Hewlett Packard 9825-T desktop computer met the majority of our needs.

## SOFTWARE CONSIDERATIONS

The specifications of a hydrographic/navigation software package will be dependent upon the developers requirements. Our considerations included multi-navigation aids, multi-range processing, multi-projection options, depth data acquisition, fix mark generation at a predetermined time or distance, data quality monitoring, dynamic calibration and peripheral outlets for plotters, printers, and monitors.

Numerous navigational aids are available with a few becoming the industry's most commonly accepted and proven units. Fortunately, most navigational aids provide distances measured in meters and can acquire several ranges simultaneously with very little remote monitoring from a host computer or operator.

The most common multi-range processing used is a least squares adjustment, using the observation method, whenever three or more ranges are available for use in the positional computation. This method has proven very satisfactory and is easily resolved by computers in several computational iterations. Furthermore, with the expansion of more range data acquisition developments today, the observation method easily accomodates this increase in data.

Several commonly accepted geodial mapping projections were considered and incorporated as the coordinate base for all computations. This included Transverse Mercator (T-MERC), UTM (Universal Transverse Mecator), Lambert, and ASP (Alaska State Plane) projections. This was deemed necessary to provide a working coordinate model in any local datum desired.

To facilitate a number of echo sounders available today into the software, a difficulty quickly became apparent. Due to the differences of each echo sounders acquisition methods and data handshaking to and from the host computer, it was impossible to integrate all possibilities into the software/hardware configuration. Project criteria controls the type of echo sounder used and interfacing of the echo sounder is performed at that time.

A fix mark generator (closure signal) was determined necessary to provide a contact closure or a 5 volt TTL pulse with variable time duration for other data acquisition equipment, ie. seismic recorders. This contact closure is controlled or fired from the host computer either at a specific time or time interval or at a specific distance traversed. The computer uses milliseconds (1/1000 of a second) as it's counting base for the internal clock. This gives a resolution well within the requirements of most hydrographic related jobs. The distance controlled firing time option is computed by continuously checking the distance travelled compared to the distance to go or the distance desired. When this distance to go becomes less than the movement the marine vessel will travel before acquiring new range data, a millisecond counter will be computed and initialized based on the predicted arrival time to the desired position. When this time occurs, the computer will reinitialize the navigation aid, generating ranges and position for the desired location. This now gives a recorded position that coincides with other data recorders that may be linked through the contact closure.

Transferring data to and from the host computer and peripherals can become a very time consuming problem. Since the time necessary to acquire data and to process it is a cyclic function, required for every update. Any and all time lost through unnecessary software and hardware configuration will have a deterant affect yielding an increased update rate on the speed of data acquisition. Thereby creating an undesireable effect of acquiring less than maximum available data. For maximum execution speed of the software, the programmer must remain aware of the importance of efficient software subroutines. This will have a two fold affect, short and efficient subroutines will execute faster and will use less computer memory. The additional memory can be used for data storage and/or program code. Peripheral data transfers can be controlled by several different methods depending on the peripheral's capabilities. If the peripheral has a built-in buffer (memory), a high data transfer rate can be used to transfer data into the buffer. The peripheral will then use the data independent of the host computer. Caution must be observed as these high rates can cause data to become lost or erroneous.

A faster, more reliable, and independent method, free of buffered peripherals that usually cost more, is through utilization of the computer's ability to transfer data through intelligent I/O's (input/output lines). This method allows usage of slower transfer rates, insuring minimum transfer errors, to unintelligent peripherals and is transparent to the operator. Thereby causing little or no hinderance to the execution time.

The importance of monitoring and verifying the validity of data acquired has been known by the surveyor since the introduction of surface geodesy. The same is true for today's prudent navigator. The navigator must have a way to check the quality of his data as to insure the continuity and the performance of the survey. The most widely used method of verifying a navigational aid is through acquisition of redundant data. This would consist of using ranges from three or more separate and independent remote sites located at known locations. The check is through comparing the computed position with respect to the additional acquired ranges. The residuals resulting from the lease squares adjustment is normally used as a validity check. A single quantitative numeric value can be computed from these residuals by square rooting the sum of the squares and dividing by the freedom of movement. This is displayed continuously for the operator as a quality control aid. If only two ranges are present at the time of computation, a different check is performed consisting of computing the internal angle of intersect. If the angle becomes less than thirty degrees or larger than one hundred fifty degrees a warning signal is generated for the operator. This limit of intersect angle will prevent degradation of the system's accuracy from becoming less than half of the navigation aid's resolution. Other methods of verifying quality data acquisition is through track plotters, velocity consistency, radar images, and other navigational aids. These could be any other positional equipment such as radio, acoustical, or satellite. These units provide a better means of a quality check than does the above mentioned plotters, radar images, etc., since they are capable of acquiring data for direct comparisons.

More recently, the concept of dynamic calibration of ranges at sea has emerged as a viable and quantitative method for calibrating ranges. The advantages of this method of calibration consist of survey site range readings, remote sites need not be moved to a known baseline, radio signals travel their normal seapath, and recalibration is easily performed when necessary. To compute accurate calibration values, the range readings must be consistent and acquired over a large area of the survey site. Also, three or more ranges are necessary to perform a computation as the redundance of data obtained provides the mathematical feasibility of computing the error contributed by each range.

## CONCLUSION

Completion of a hydrographic/navigation acquisition package is only a small part of the total development necessary to

support hydrographic surveys. Data reduction or post-processing is itself a separate development and requires considerable amount of time and support for full processing capabilities. Another consideration is the specialized hardware used in hydrographic surveys as well as the environment it is utilized in. Support of this hardware has become very extensive and costly, both for the navigator/surveyor and the client. Coupling data post-processing and hardware support together along with the continuing revisions necessary for software growth and development, it becomes evident that other commitments must be addressed to provide a complete hydrographic package.

# HYDROGRAPHIC DATA PROCESSING USING HEWLETT PACKARD 200 SERIES COMPUTERS

Gerard Zieleman
Comstar Inc.
10520 Meadowglen
Houston, Texas 77042

## BIOGRAPHICAL SKETCH

Gerard Zieleman is the Executive Vice President in charge of Marketing at Comstar Incorporated. After finishing his electronics studies in Rottendam, Netherlands, he joined I.N.A. in 1960. While being the Decca representative in the Netherlands, he was responsible for the first operational Hi-Fix chain used for the construction of the new harbor entrance for Amsterdam. Since then his work has been related to Hydrographic Survey and Dredging positioning systems. From 1975 on, he has been working with the automation of these systems. On behalf of Decca, London, he was involved in positioning and automation projects world-wide. He is a member of The Hydrographic Society, Dutch Branch.

## ABSTRACT

The Surveyor-200 series survey data acquisition and processing systems are designed for small-to-medium sized vessels. The system displays the vessel track on a graphics monitor, records position, depths and gauge corrections together with time and line number on a cassette recorder or other user selectable media. The system also draws minimum depth on the plotter at non-overlapping intervals while surveying.

## INTRODUCTION

The survey system is in operation in the Detroit and Memphis Corps of Engineer Districts. The Memphis District has also obtained pre and post processing systems. Comstar has designed and developed real-time data acquisition systems as well as off-line processing systems for hydropgrahic, oceanographic and related applications such as dredging surveys based on the various combination possiblities of the 200 series.

The system discussed here is based on a Hewlett-Packard 200 series computer, graphics display, plotter and magnetic recorder used for on-line survey as well as off-line processing. The system was designed to the specifications of the U.S. Army Corps of Engineers of the Memphis District. The special feature of this system is that while on-line every single depth will be recorded, 10 per second. The off-line or post processing program has different options that allow the computer to handle the enormous amount of data.

## ON-LINE PROGRAM

The depth is recorded ten times per second, the position once per second, and at a user definable line interval the gauge correction may also be recorded. The survey lines can be defined using start and end coordinates as well as defining bearing and distance. This allows both angular and parallel line definitions. With the aid of soft key options, the operator can select real-time tracking on the screen with respect to the pre-selected survey-lines (figure 1) or select a left/right indicator (figure 2) with respect to the current survey line. The depth, x and y position and time will always be displayed on the monitor. We will not go into details as far as the on-line program is concerned, but pay more attention to the off-line processing.

## OFF-LINE PROCESSING

A new survey file will be created from the magnetic media containing the original survey data. This new file can be created using distance and depth processing facilities within the program. The distance editing facility is mainly for editing out depths that are not needed because of the density of data recorded. Depth processing is for the removal of bad depth data created by debris, air bubbles or other causes. The exact position of the depths will be computed by interpolation of the recorded positions.

The raw data file will still remain and can be used again if different criteria for distance or depth processing is required, or in the event uncorrectable mistakes were made during editing.

The main use of this data is to produce depth profiles (figure 3), charts and to compute dredging volumes. Depth and distance scales are selectable for drawing profiles and templates for volume computations. Charts can be drawn plotting depths or elevations as well as user defined symbols. The distance between consecutive depths that are plotted during charting can be selectable.

When charting, we assume to have a pre-drawn annotated chart on the plotter. This chart could be an annotated aerial photograph as in the case of the Memphis District. The operator just has to digitize two points on the chart by moving the plotter pen to the two points and digitizing them. The program will take care of scale, skew and axes lengths.

The volume is computed using a template that is defined by the user. The template has 4 sections, defined by 5 distances and depths (or elevations). Each section is defined by its own starting point and the starting point of the next section. This allows for the 4 sections to have

their own slopes and lengths. Different colors can be used to draw the profile (figure 4) and an option is provided to color in parts of the profile to distinguish areas that need dredging.

## EXAMPLES OF PROGRAM 200 VERSIONS

As far as post processing programs are concerned, there are options as required by different customers to suit their particular requirement. A few options will be briefly explained hereafter.

If a cross profile is required with respect to sea level an option is provided to draw the elevation profile rather than the depth profile.

A second option offered is for graphically editing the data collected. This option allows for the simultaneous editing of the vessel true course and the bottom profile. The vessel course is displayed in the upper half and the depth profile is displayed in the lower half of the display. The user can move from record to record or display to display for ease of editing. Being able to view the data and edit out offending positions or depths makes the editing process much easier and faster.

The examples attached show: spikes in position as well as the depth (figure 5); position spike removed by graphical editing (figure 6); depth spike removed by graphical editing (figure 7).

## SUMMARY

Fast processors and state-of-the-art programs are able to offer systems for all kinds of applications for on-line, real-time data acquisition and off-line post plotting which suite the special requirements of the customer.

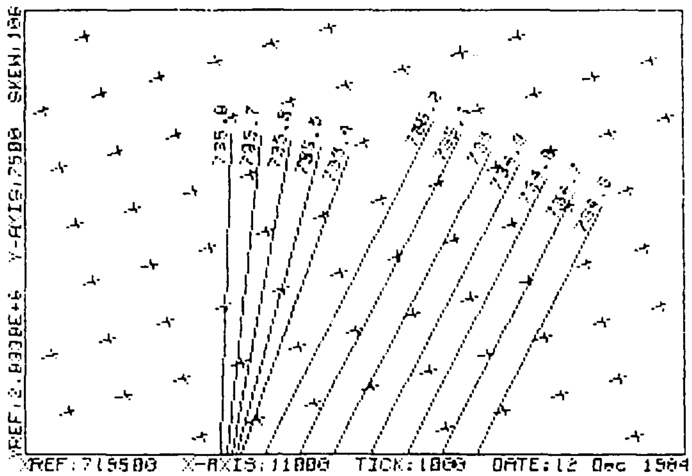



figure 1 - Plan View display showing survey lines

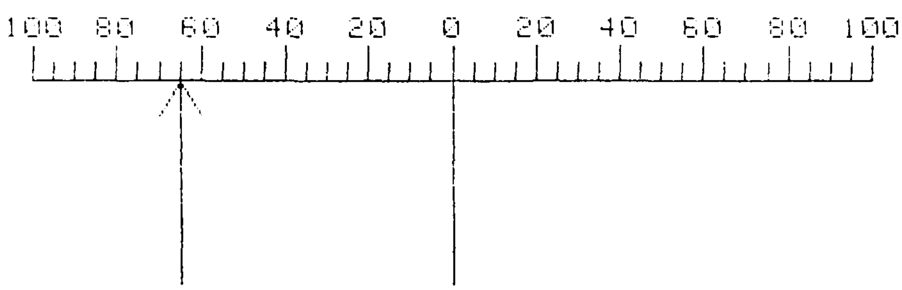



figure 2 - left/right indicator

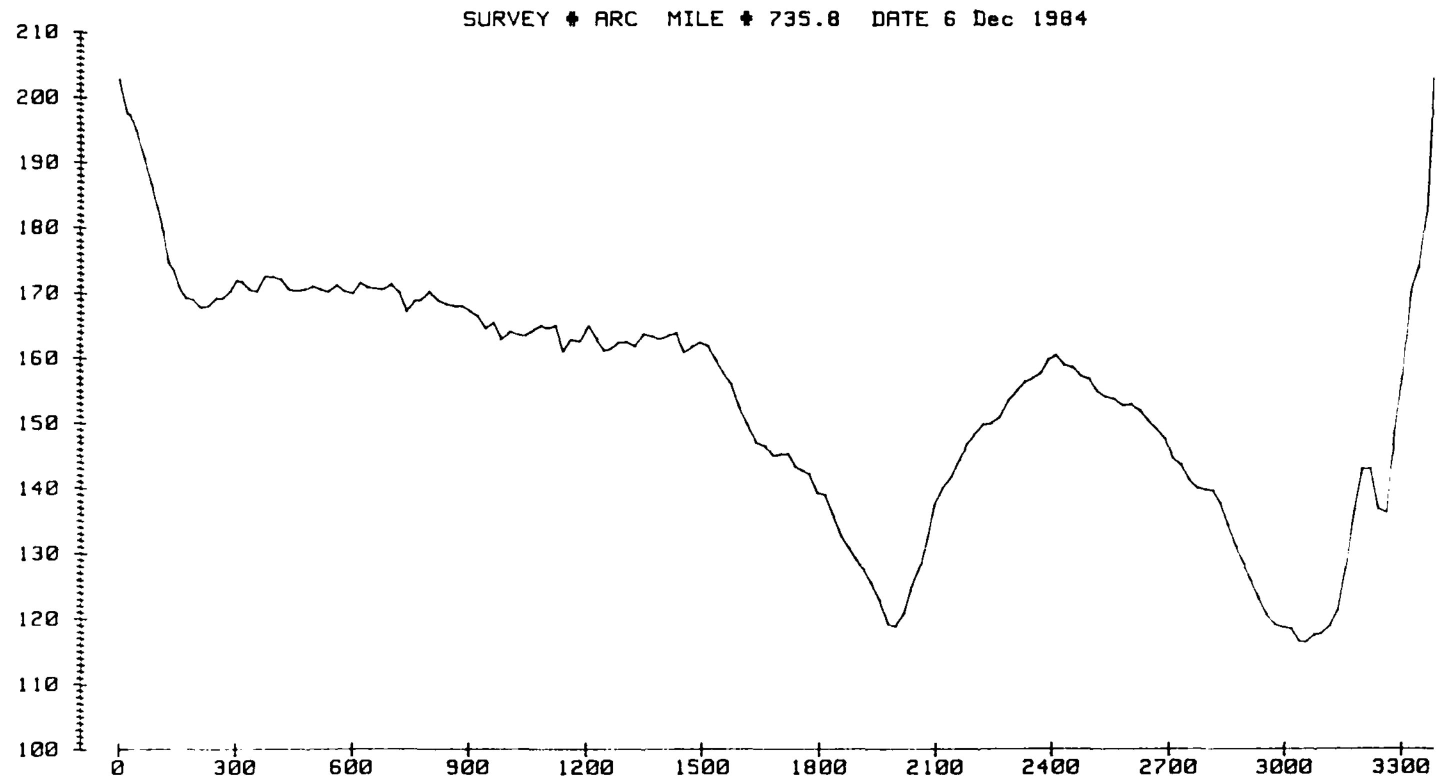
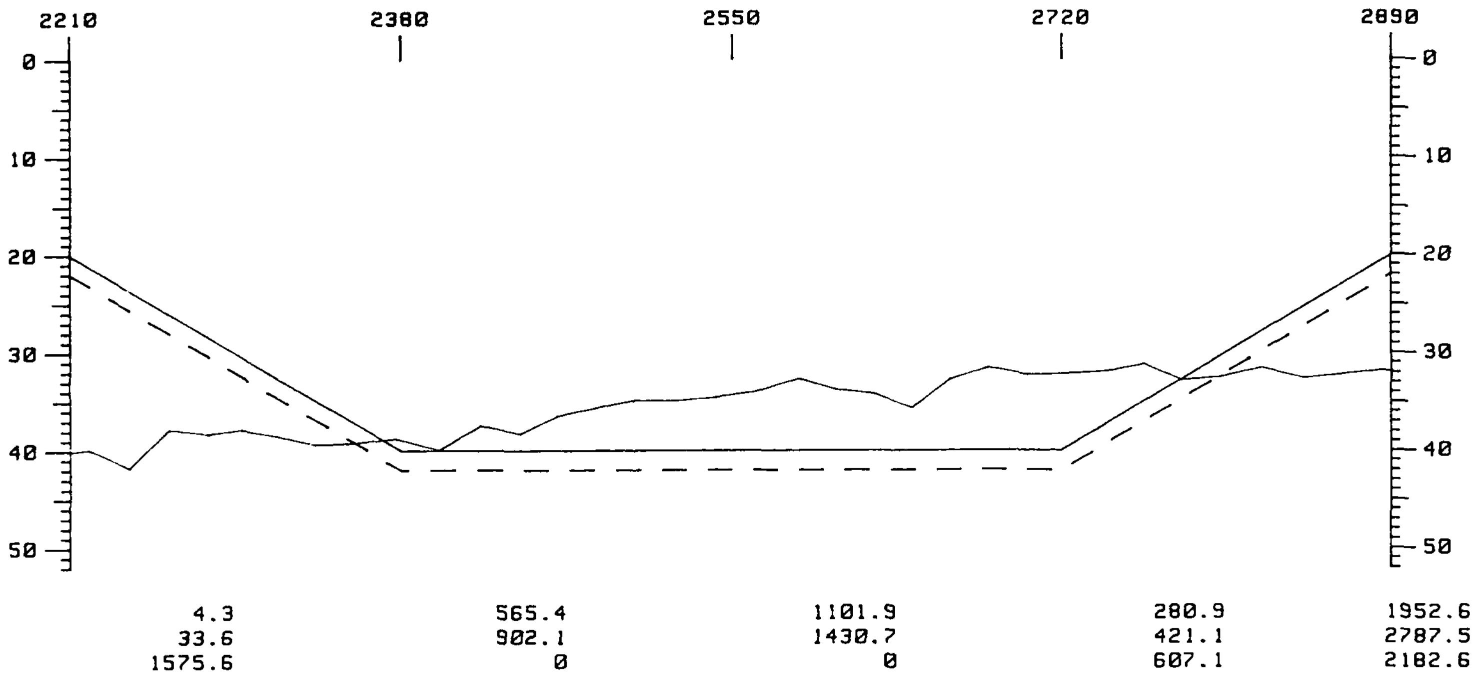



figure 3 - bottom profile

MEMPE
SURVEY # ARC   MILE # 735.8   DATE 6 Dec 1984




Vertical Scale 1/200   Horizontal Scale 1/1000

figure 4 - template for volume computation,
areas are displayed at bottom

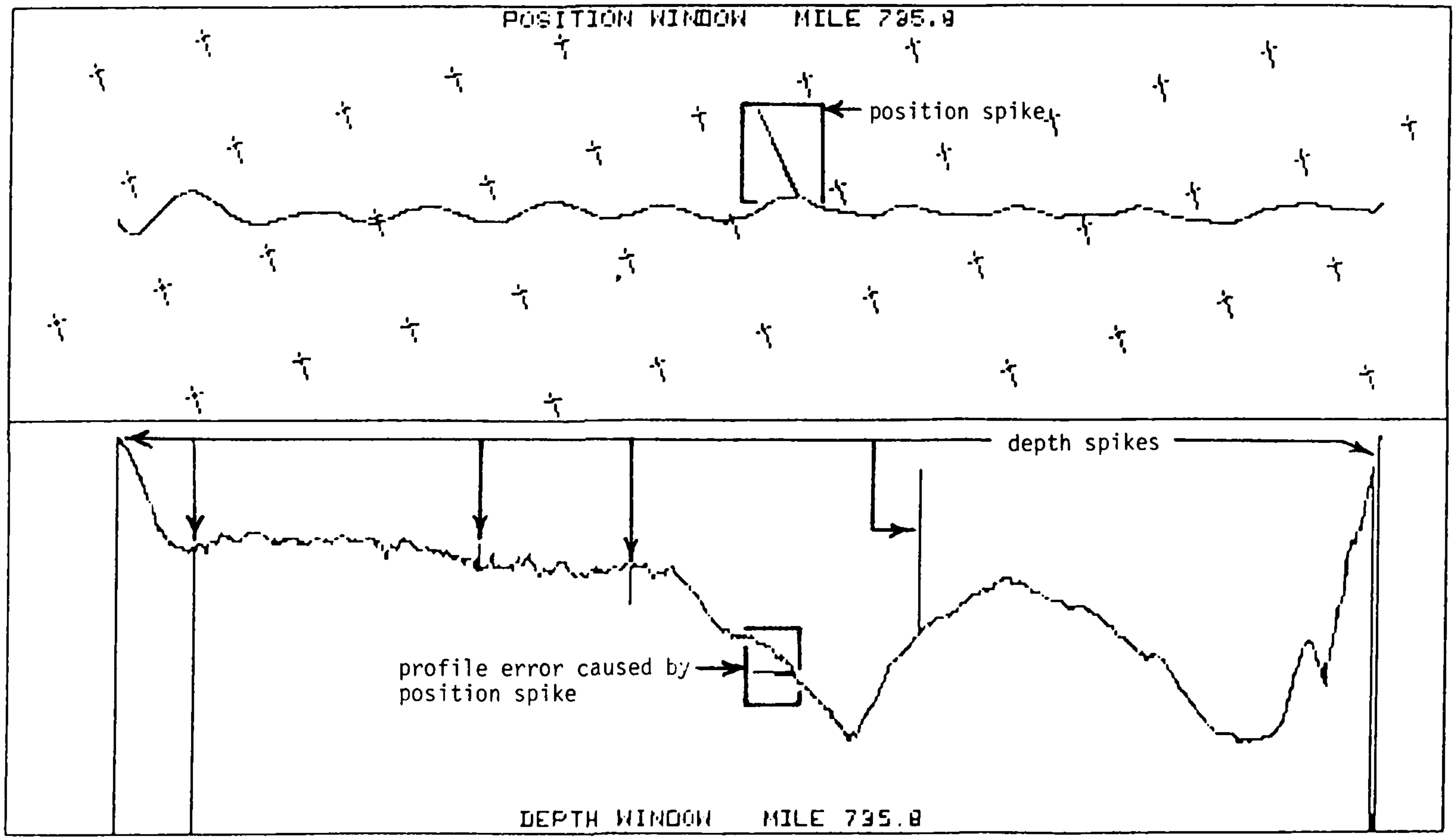



figure 5 - position and depth errors

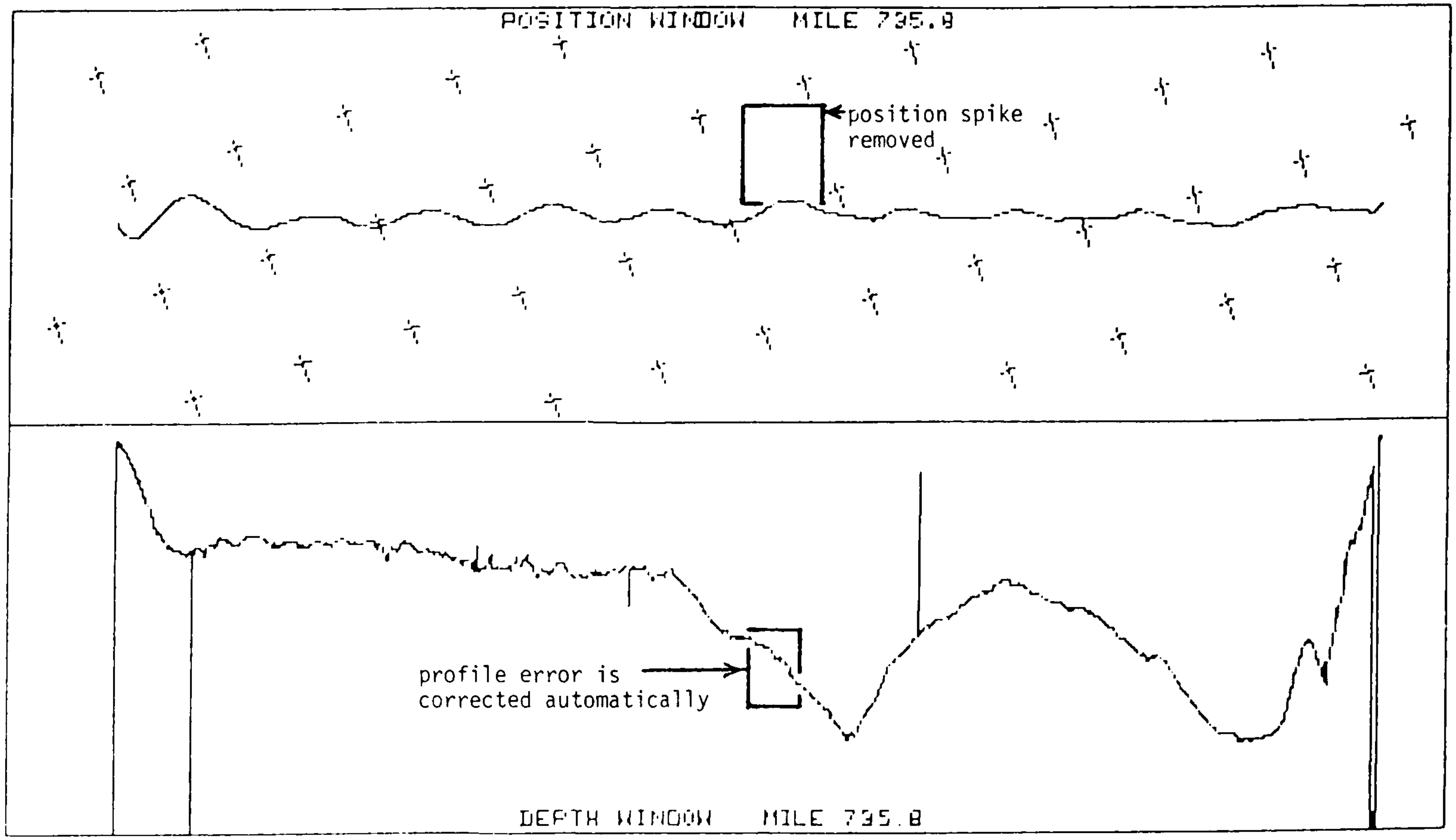



figure 6 - position spike removed

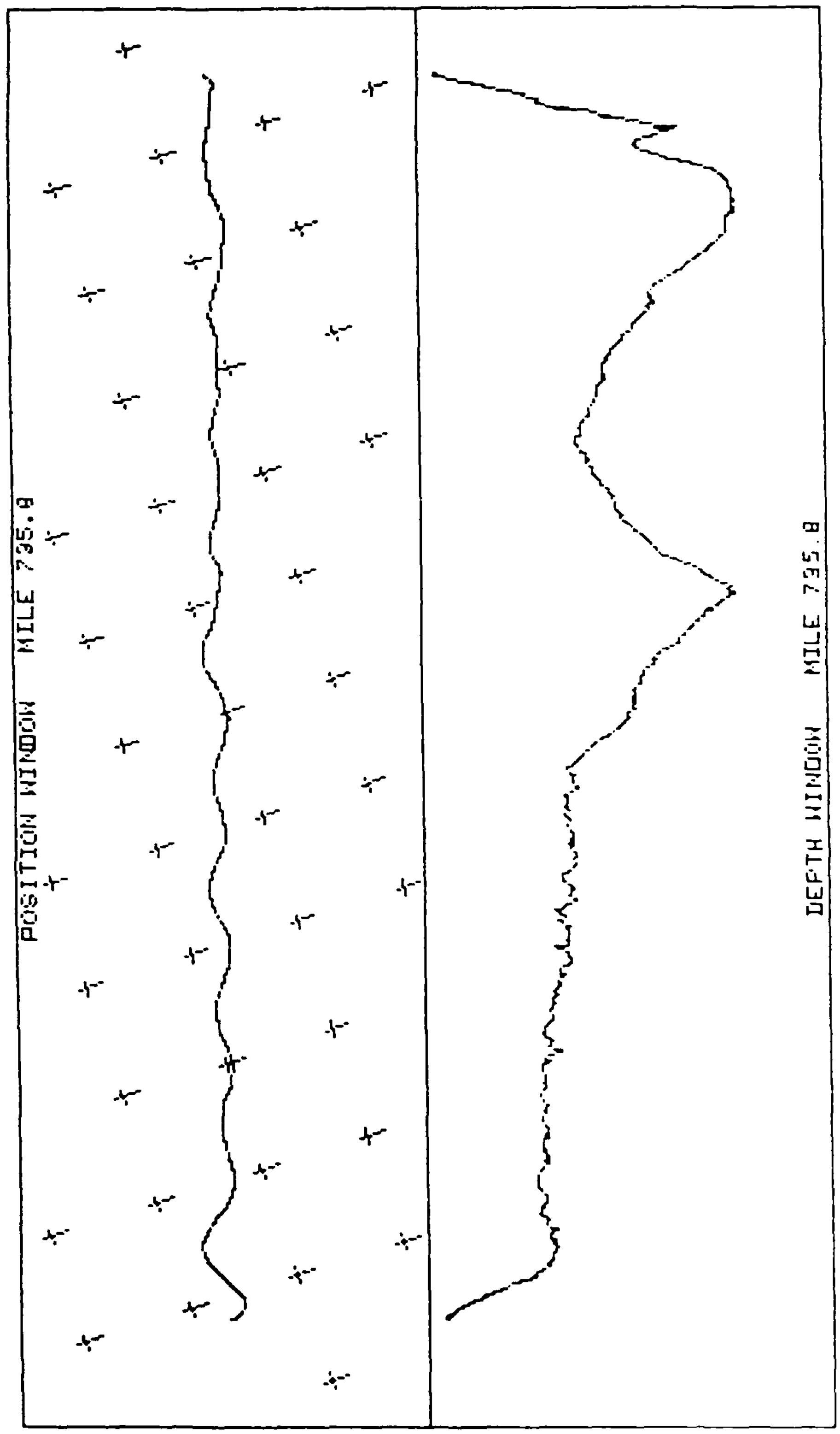



figure 7 - all depth spikes removed

# PARALLEL LINE HYDROGRAPHIC SURVEYING

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## BIOGRAPHICAL SKETCH

Jack Bechly is Chief, Waterways Maintenance Section, Navigation Branch, Operations Division, Portland District, Corps of Engineers. He is a BS graduate in Civil Engineering from Seattle University. Since graduation in 1959, he has been with the Corps of Engineers in Seattle and Portland Districts. After several years in comprehensive planning, he has worked with the Channels and Harbors O&M program since 1968.

## ABSTRACT

The Portland District uses the Parallel to Channel Line hydrographic surveying concept to accumulate the bulk depth data. Traditionally, cross-line or cross-section type data accumulation was/is utilized by many parties. The benefits of the parallel line method, particularly in sand-wave prone areas and with higher speed vessels, is discussed.

## GENERAL

The Portland District Corps of Engineers has two surveying missions. We accomplish in-house and contract surveying to support our engineering and design mission and we accomplish mostly in-house surveying to support our channel and harbor operation and maintenance mission. Topic of this paper will deal specifically with the channel and harbor O&M Mission.

To support our O&M mission for channels and harbors we operate five surveying crews. Four of these crews are hydrographic crews that work in the waterways of the Portland District. The fifth crew is primarily a land crew that updates and maintains our land control net and also accomplishes site surveys for disposal areas and other features connected solely to the channel and harbor maintenance program. Of the four hydrographic survey crews, one operates from a 65' aluminum displacement hull vessel, the "HICKSON". This boat surveys the Columbia River Estuary and the larger coastal entrances. A second crew operates from the 48' SES vessel "RODOLF". Their area of operation is the Columbia River from the estuary to Portland and a barge channel from Portland to Bonneville Dam. A third survey crew operates out of a 26' aluminum displacement hull, the "PUFFIN". This crew is home based at Coos Bay, Oregon about 200 miles from the District Office on the southern Oregon coast and accomplishes entrance and inside work for the coastal projects. The fourth hydrographic survey crew is flexible in that they operate out of three or four separate vessels. When backing up the HICKSON and RODOLF crews for surveys for the Columbia River and the large coastal projects, they operate out of the 52' vessel "NORMAN BRAY". This boat is equipped with the Ross Channel Sweeping System which consists of sixteen transducers mounted on two air operated booms that swing down from a float pushed by the NORMAN BRAY. This system is utilized for areas of rock excavation, etc. The fourth crew also operates a 19' inboard boat for back up surveys in the side channels to the Columbia River and smaller out-board craft for pick-up surveys in the smallest projects and shallow waterways, such as the Lower Cowlitz River.

Three of the vessels and their crews utilize the Racal Autocarta II Hydrographic Surveying System. In addition, the vessel HICKSON is equipped with a Krupp-Atlas Heco-10 Swell Compensating System. The HICKSON operates in a surveying mode at about 14 knots. The RODLOF operates in a surveying mode generally from 27 to 30 knots with some cross-line surveys being accomplished at from 15 to 25 knots. The PUFFIN on the Oregon Coast operates at about 20 knots in a surveying mode with the exception of some cross-line surveying at slower speeds. The other small boats operate generally at slower speeds because of the lesser scope of the surveys being accomplished. For the fourth crew, we utilize an older Autocarta "S" System on the vessel NORMAN BRAY, but on the smaller craft we utilize plane table generally with electronic positioning (trisponder system). The surveys are then digitized in the office for computer plotting.

All surveys, whether automatically digitized and processed on-board or digitized in the office from the smaller craft, are plotted out on aerial ortho photo background cronoflex sheets on a large flatbed plotter by the Data Processing Center in the District Office. Scales vary depending upon the project being surveyed. Soundings are plotted only to the nearest foot on our actual hydrographic survey charts. Sounding data is accumulated at one-tenth foot accuracy with the rounding taking place in the micro- processor before plotting.

## PARALLEL LINE SURVEYS

The majority of the time Portland District Hydrographic Surveys are accomplished via the parallel line approach. That is, we survey at high speed parallel to the navigation channel alignment. We accomplish bank to bank cross line surveys only on a periodic basis (once a year) in the Columbia River and at some other isolated coastal locations to show the location of the thalweg of the stream and compare it to the total width of the wetted perimeter. Generally, cross line surveys accomplished in this manner are used only for thalweg and channel shoaling trends and assistance in locating flow lane disposal areas and not for quantity computations. Our parallel line surveys are run in various densities, in other words, we have a standard seven-line condition survey which means that we accomplish a line down the center of the channel, the quarter line of the channel, the cut lines and one line outside the channel. For pre and post dredge payment surveys, we add extra lines on the 1/8 lines of the channel, one extra line on each side of the channel toes, or cut lines, and one extra line on the outside of the channel limits on each side. By utilizing this method we have found that we can use the maximum cruising speed capability of our survey craft and accomplish many more line miles of electronic data accumulation per hour.

Generally, the 700 miles of channel and harbor projects in the Portland District have been constructed in sandy materials. Silts, or fine materials are a distinct minority and only occur in some isolated locations such as upper Coos Bay, Oregon, Portland Harbor, Oregon, and small entrance channels at some of our boat basins. The sandy materials together with the relatively high velocities experienced in our river projects (four to nine knots) is conducive to sand wave formation. Parallel line surveys enable us to keep a close watch on the development and movement of these sand waves and to manage our maintenance operations accordingly. A graphic example of the template layouts for parallel line surveys and for cross-line surveys are illustrated on figure 1.

An aspect of high speed parallel line surveying that at times leads to problems is the performance of this type of survey near developed waterfront facilities such as pleasure craft marinas, houseboat moorage areas, etc. Although these developments are generally at a minimum, and mostly

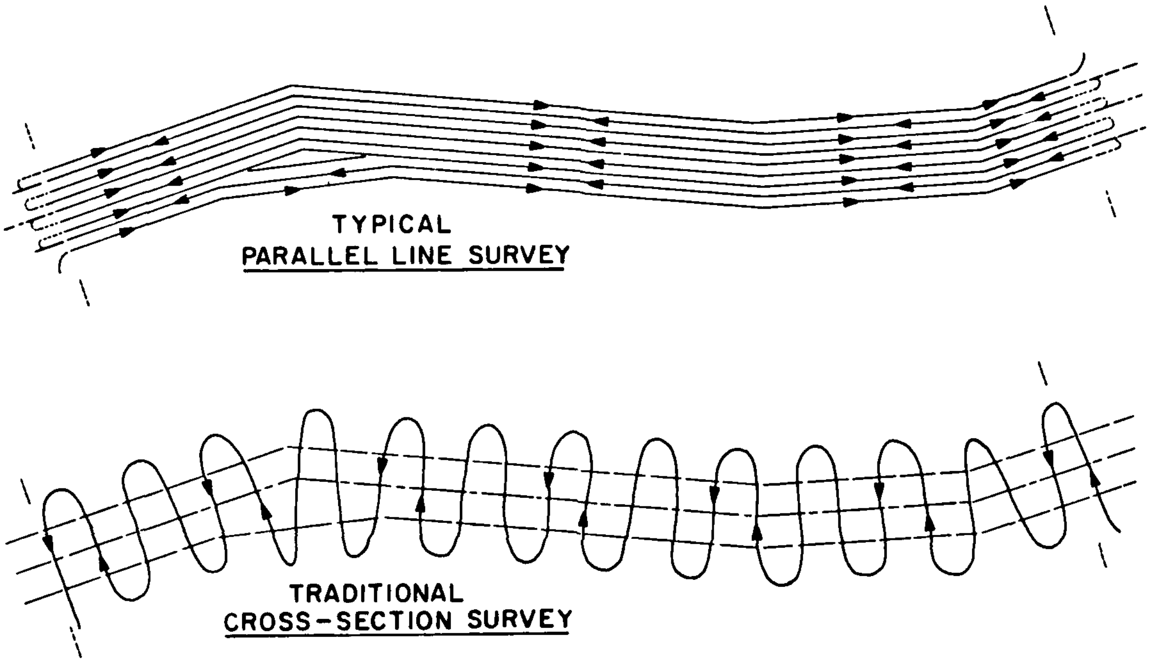

TYPICAL
PARALLEL LINE SURVEY
TRADITIONAL
CROSS-SECTION SURVEY

FIGURE I

in protected areas such as inside small boat basins with rock breakwaters or in side channels to the main river channel, there are areas in our channel and harbor projects where a displacement hull vessel would have to proceed at relatively slow speed regardless of the method of survey accomplishment, i.e., parallel line or cross line. The survey vessel RODOLF, being a SES vessel, can travel at 28 to 30 knots in the surveying mode in the close proximity of these developments without conflict because of its relatively flat wake. Thus, we are able to utilize the full benefits of the SES vessel by combining the parallel line surveying method with its lack of wake for accomplishing the surveys at the maximum possible speed.

## CROSS-LINE SURVEYS

Traditionally, in many other districts and by private industry, hydrographic surveys, particularly for pre and post dredge payment purposes are accomplished in a cross-line or right angles to the channel-limits basis. These surveys are accomplished at a template interval depending on the frequency of quantity cross sections needed and the accuracy specified. A positive aspect of the cross-line type surveying method is that every digitized sounding in modern electronic surveying systems (10 per second) can generally be utilized in the overall cross section plotting and quantity computations in District office processing. However, the surveys in their very nature require the survey vessel to proceed at relatively slow speed in making the continuous 180° turns at the end of each surveying line. The shortness in surveying line lengths also is not conducive to high speeds. Speeds must be kept constant in a cross-line survey in order to assure the lack of warping of the processing of the analog trace and digitized readings in the data accumulation and processing. As many of our projects involve coastal entrance bars, or exposed ocean embayments, cross-line surveys are not appropriate nor safe. Surveying vessels would be required to traverse the areas between entrance breakwaters or in embayments generally parallel with the ocean swells at slower speeds which would require more favorable weather conditions than those during which parallel line surveys can be accomplished at right angles to the ocean swells and at higher speeds.

## SHOAL BIASING

In shoal-biasing, the processing of the analog trace is accomplished in 1 to 5 second blocks of time at the operator's will, based on the requirements or the features of the particular site. The computer selects the shoalest sounding in these predetermined blocks and plots it in its exact position on the printed sheet. It interrupts the regular spaced sounding plots when it detects a shoal to plot that sounding correctly. This will result in a longer space on one or the other side of the soundings on the printed survey which will appear at first glance to be a skipped area. Shoal biasing in this sense is different from simply plotting the "mean" or "sample" depths on a continuous analog trace at a uniform time interval. It is also the exact opposite of using deep-biasing software to plot only the deepest depths in any specified interval of time. Most traditional surveys, be parallel line or cross-line, use the sampling type of data processing and plotting.

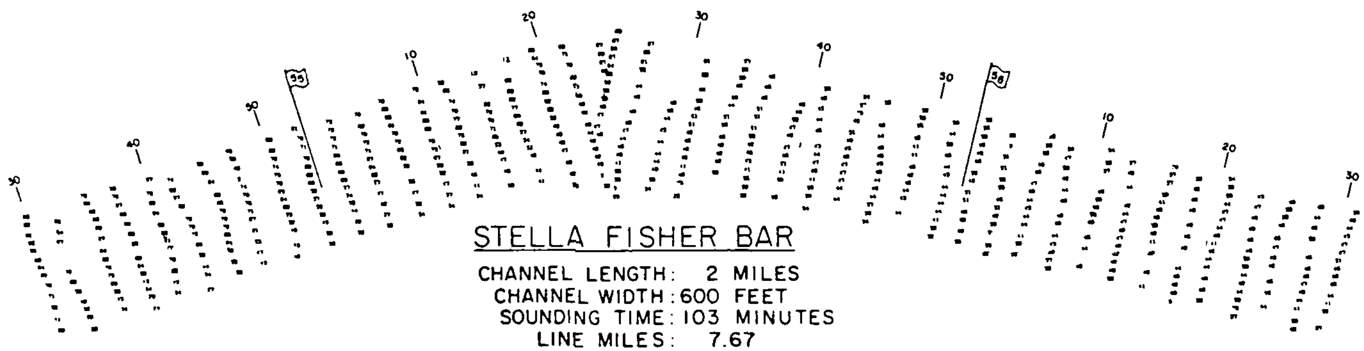
Generally, all of our surveys are accomplished using the shoal-biasing software. We feel as the agency responsible for maintaining and preserving navigation channels for shipping interests, our mission is to insure that these channels have full project dimensions to the full extent practicable. Therefore, shoal areas must be quickly and accurately

identified and traced over a period of time to allow for efficient management of the channel maintenance activities. This is particularly true with sand waves as they generally form at right angles to the thalweg of the stream and tend to multiply and move downstream in their growth progression. By utilizing the shoal-biasing system in our pre and post payment surveys for contract operations we are clearly transmitting the message to our dredging contractors that maintenance of the channel to the full pay depth without any residual shoals after the dredging operations is of the highest priority. We feel that the payment of material removed by the cubic yard must be tempered by the ever present knowledge that the overall goal of the contract is to remove all shoals to the project depth.

A particularly desirable feature of the shoal biasing program is that it keeps an accurate plot of the sand waves with the parallel line surveying method. A manager can tell at a glance the existence and heighth of sand waves, the number of them, and in viewing several successive surveys, can determine trends in their progression and growth. This also allows sound decisions to be made regarding the type and scope of maintenance activities required to provide consistent channel depths: i.e., for small isolated sand waves a hopper dredge may be the most efficient plant to come and knock the tops off and leave. But for numerous flat topped or lengthy sand waves, it may be more efficient to schedule pipeline dredging plant in the area. Shoal biasing clearly defines the existence of any "high" spots in a post dredge survey for the benefit of determining acceptability for physical completion and payment purposes. In this sense, it is beneficial to both the contractor and the project owner in that it requires only the minimum effort to go back, locate and clear these high spots.

## QUANTITIES

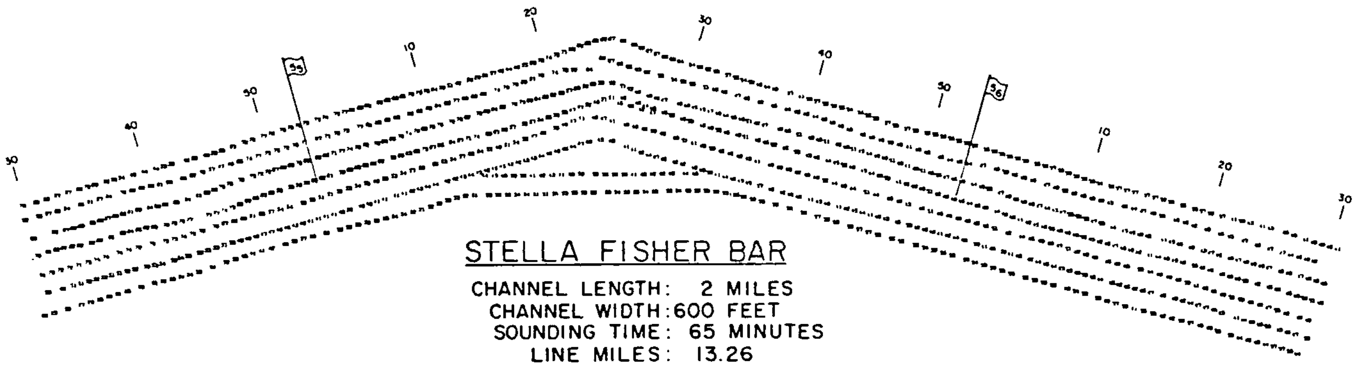
As practical managers of extensive channel and harbor projects, the two main products of a hydrographic survey are shoaling trends and quantity determination for payment purposes. Accurate quantity determination is very important to both the project owner and the contractor. At first glance one would think that the cross-line type survey with its ability to utilize every digitized sounding (approximately 10 per second) in the preparation and processing of cross sections would be by far the most accurate and reliable. This is the underlying reasons why most traditional hydrographic surveying interests utilize the cross-line method of surveying. The fallacy in the above premise is that most interests perform all surveys by the cross-line basis over and above those simply needed for determination of quantities. In our view, only quantity surveys, if any, should be performed by cross-line surveys, and the remainder performed by higher speed parallel line surveys which enable the accumulation of many more line miles of surveying data and a greater readout of the river channel bottom characteristics. We have compared cross-line surveys and the quantities derived therefrom with our parallel line surveys and have found that they generally agreed within a 0% - 5% range, and that the range can be both the plus or minus side which means essentially, the quantities determined by either of the above methods are closely comparable. To determine pay quantities by the parallel line surveying method, the processor does not have available every digitized sounding but has to rely on software to determine the template location and to read at least two digitized depth readings on the parallel line at or near the intersection of the cross section template, mean these soundings, and construct mathematically the cross sections from this data. At selected locations throughout the district we have accomplished surveys by both methods utilizing the large and small vessel systems, computed the quantities and compared the results and found that we were within the margin of accuracy stated. A recent test with the 48' RODOLF in the Columbia River achieved the results shown on figures 2 and 3.




STELLA FISHER BAR

CHANNEL LENGTH: 2 MILES
CHANNEL WIDTH: 600 FEET
SOUNDING TIME: 103 MINUTES
LINE MILES: 7.67
NO. OF SOUNDINGS PLOTTED: 590
CUBIC YARDS ABOVE -55 FEET: 1,610,952

FIGURE 2




STELLA FISHER BAR

CHANNEL LENGTH: 2 MILES
CHANNEL WIDTH: 600 FEET
SOUNDING TIME: 65 MINUTES
LINE MILES: 13.26
NO. OF SOUNDINGS PLOTTED: 1001
CUBIC YARDS ABOVE −55 FEET: 1,616,475

FIGURE 3

## SUMMARY

We have been utilizing the parallel line surveys as our primary method of hydrographic survey data accumulation in the Portland District for over 20 years. It has enabled us to live within the severe personnel and funding limitations imposed in recent years and still provide the amount of line miles of surveying data required to maximize the accuracy of the payment process, to maximize our efficiency in determining shoaling trends, and manage the scheduling of dredging operations, and to realize overall cost savings for our entire program. The utilization of super high speed vessels such as the SES RODOLF dramatically enhances the advantages of the method. We strongly recommend its adaptation wherever possible.

# THE ADAPTATION OF TRADITIONAL HYDROGRAPHIC TECHNIQUES TO PRECISE DREDGE SURVEY

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## BIOGRAPHICAL SKETCH

Colin G. Weeks was a specialist hydrographic surveyor in the Survey Service of the Royal Navy from 1950-67, before coming to the U.S. as Chief Surveyor of Decca Survey Systems, Inc. in October 1967. Since then he has divided his time between hydrographic surveys and the development of automated hydrographic systems, having been responsible for the development of Autocarta X, Hydrocarta, Hai-carta and, most recently, HAIcarta.

## ABSTRACT

The object of a conventional hydrographic survey is to ensure the safety of navigation, which it does by biasing the errors so that the soundings charted show less water than in fact exists. This is the cost-effective solution in normal hydrography since additional equipment is required to achieve precision rather than safety - and the mariner's need is for safety. A dredge survey however needs precision, since the payment of large sums hinges on a comparison of surveys. The dredge operators are aware of this and are making the necessary investments; it is suggested that the Government needs to do this also since the taxpayer will suffer - by millions of dollars - if a 'safe' survey is used for the before-dredge and a 'precise' survey for the after-dredge.

The paper discusses some of the factors which need to be considered.

## INTRODUCTION

One consequence of the recent partial transfer of dredging responsibilities from the Government to private industry has been an increased emphasis on dredge surveys. When the Government owns the dredge it is probably sufficient to judge its performance on a count of hopper loads or of production hours, since the purpose is only an internal transfer of paper funds. When however the Government is paying tens of millions of dollars to a private contractor it has a prime responsibility to the taxpayer to ensure that the money has indeed been earned, and a lesser one to the other bidders to ensure that the terms of the bid documents have been complied with. It is suggested that these responsibilities can only be fulfilled by a comparison of before- and after-dredge surveys, conducted either by the Government or a professional survey organization, independent of the dredge contractor. The dredge contractor will in fact be carrying out his own surveys - he has to, to make sure he does not overdredge - but to rely on those for anything other than progress payments is asking too much of human nature.

To give an idea of the dollar value involved, in 1984 the Stuyvesant Dredging Company was low bidder on a contract to remove 4,329,000 cubic yards from the entrance to Galveston. The channel is 10 miles long by 800 feet wide and the value of the contract was $11.3 million; based on these figures, taken from the International Dredging Review (Jan./Feb. 1984), it follows that the cost of deepening the channel was $4 million per foot. This is a staggering figure to someone who has spent his life in what might be called 'conventional' hydrographic survey - surveys leading to the publication of a navigational chart - since none of these surveys had an 'accuracy' even approaching a foot. This was not their purpose - the object of a conventional survey is to produce a safe chart, not a precise one, and where there is any doubt about an error it is biased on the shoal side. It follows therefore that the conventional procedures should not be blindly followed in dredge surveys but should be carefully considered and modified as necessary.

The paper that follows is an attempt to do this. Since it recommends expenditures it is proper to declare one's interest; Hydrographic Associates, Inc. develops software for hydrographic systems but has no interest in the sale of positioning systems, depth sounders, heave compensators, tide gauges or sound velocity sensors.

## POSITIONAL ERRORS

For convenience the error sources are categorized as positional, depth, or computational but it is not intended to spend much time on positioning problems. Precise positioning is a requirement of many offshore activities and there is an extensive literature covering its use. It will therefore be assumed that an appropriate positioning system is in use, that it has been correctly installed and calibrated, that the shore stations are correctly co-ordinated and that they give

adequate geometry. Two points however must be mentioned. Firstly, the results will not only be plotted on a very large scale - 100 ft to the inch is typical - but the end area calculations will be based on fractions of a foot of travel. This requires not only that the positioning antenna be vertically above the echo sounder transducer but that it should be possible to correlate in time the position and depth data, to eliminate a speed dependent error. With microwave positioning it takes a finite period to measure each range and the length of the delay between measurement and the arrival of the range in the computer will vary with the range, the number of ranges measured, the propagation conditions, the number of users and the method of data transmission. Variable delays of this type cannot be accurately corrected in the computer and the problem must be solved by the manufacturer of the positioning system.

The other point to make on positioning is the desirability of recording redundant range data. There is always the possibility of a dispute being taken to Court and without redundancy the positions would be difficult to support. However there is more to it than that; the main use of multiple ranges should be to make the surveyor aware of positioning problems at the earliest moment so that he can do something about it.

## DEPTH ERRORS

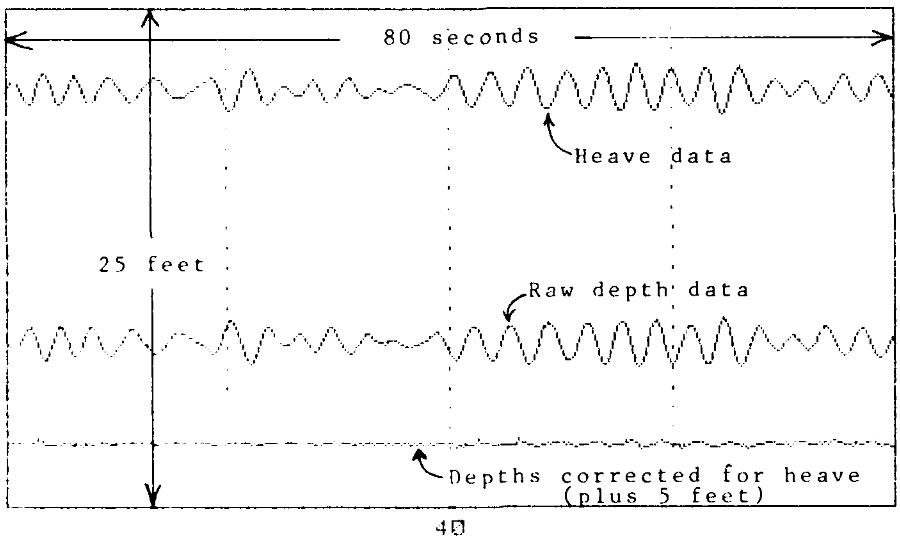
Sounder calibration. The universally accepted method of calibrating a depth sounder is the bar check; however, an experiment conducted last year raises doubts as to whether it is in fact the most precise means. Imagine a survey boat secured by the stern to the container berth in Galveston where there is a flat bottom about 40 feet deep. There was no wind, no current and the water was still. The depth was measured with a hand lead on either side of the boat, abreast the transducer, as 40.0 feet and the sounder speed was adjusted to show the echo at 40.0 feet; the bar check was then lowered to 35 feet and the echo observed at 35.5 feet - a six inch error. The procedure was repeated on a second day with the same result. Note that the error was on the safe side; adjusting the sounder to agree with the bar would have moved the seabed echo to 39.5 feet. Note also that a six inch error on the Galveston survey would have cost one side or the other $2,000,000 - depending whether it was before-dredge or after-dredge.

The suggested explanation for this is that a strong echo will tend to create a shallower echo than a weak echo at the same depth; this can be observed by varying the gain control while doing a bar check and seeing the echo of the bar move up and down. The sounder in this case was a Raytheon 719 with an $8^{o}$ transducer, giving a footprint 2.8 feet in radius at 40 feet. Thus the reflective area of the seabed was about 50 times greater than that of a 1 inch bar at the same depth.

Unfortunately the problem is more easily stated than solved. In Galveston we had ideal conditions for the hand

lead and these can rarely be found offshore. This is a problem that calls for practical research in a flooded dry dock, but one possible solution is to use a bar at a shallow depth to set the draught control and to use a sound velocity sensor to determine the speed - assuming the echo sounder has the means to enter the velocity of sound directly.

Heave correction. The principal reason why a hydrographic survey is safe but inaccurate is that the soundings will tend to be shoal by the height of the waves at the time of sounding. If the seabed is flat and the waves 2 feet high, the echo trace will apear identical to one taken in flat calm over sand waves 2 feet high. The surveyor, looking at the echo roll after the fact, therefore has to assume that he is looking at the actual seabed. As far as computing quantities is concerned the error will tend to average out; the problem for the dredge surveyor occurs when a channel has been completed but the wave action makes it appear that shoals still exist. For this reason two of the larger U.S. dredging companies have now invested in heave sensors which measure the vertical motion of the survey boat and allow the appropriate correction to be applied to the depths. The cost of such a device is substantial but is probably recovered on the first job in saving time for a big hopper dredge.




Trials of the HIPPY 120 Heave/Roll/Pitch sensor - Galveston, 6 Dec 1984

Figure 1

The two heave sensors commercially available in this country each consist of an accelerometer mounted on a stabilized platform, in one case stabilized gyroscopically, in the other by a unique pivoting system that gives the effect of a pendulum with 120 second period, so that it stays level while the boat rolls round it. The practical problem

with each is that the accuracy of the realtime output is affected by the alterations of course of the vessel - which in a normal dredge survey are frequent. In the second of these sensors this effect is mitigated by a digital filter which effectively suppresses these unwanted perturbations; however the output of the filter is delayed by 77.2 seconds so that realtime correction is impossible. This is not too serious a disadvantage since dredge quantities are normally computed offline anyway but it does require a shipboard computer to make best use of the system. Figure 1 shows data from this sensor processed off line to show uncorrected depths, corrected depths and heave. Assuming the seabed to be flat this trial indicates that the sea effect has been reduced from 4 feet to less than 1 foot - a very substantial improvement, but further trials are necessary to test its behavior under other conditions.

Proximity of tide gauge. During the Galveston contract described earlier the contractor surveys and the Government surveys agreed remarkably well in the Inner Bar Channel and in the Outer Bar Channel - but in the Entrance Channel, outside Galveston jetties, the two surveys disagreed by as much as a foot. What was more, two contractor surveys, taken three days apart, disagreed with each other by the same amount. We became involved because the software was blamed - and to prove the software right we had to prove something else wrong. This led to the investigation of bar checks mentioned earlier and also to a scrutiny of tide gauge records. There are three Government tide gauges in Galveston; two recording gauges operated by NOAA - at Pier 21, in Galveston harbor, and the Flagship Hotel, on the Gulf of Mexico - and a tide staff belonging to the Corps of Engineers at Fort Point.

When we compared records from the two recording gauges we found several days when the range of tide - the difference between the heights at High and Low Water - was a foot larger at the Flagship than at Pier 21. When you look at the chart this is an understandable phenomenon; a largish body of water in Galveston Bay is separated from a much larger body - the Gulf of Mexico - by a narrow constriction at Galveston Jetties. As the tide rises offshore water enters through the jetties, trying to bring Galveston Bay to the same level. However before this level is reached the tide has fallen offshore and the process is reversed. If then soundings taken in the Entrance Channel - in the Gulf of Mexico - are reduced by the gauge at Fort Point, where the range is a foot less, soundings taken at high water will be reduced six inches too little and those taken at low water six inches too much. Thus if the same line was run twice on the same day, six hours apart, the two lines would differ by a foot.

This is one type of tidal problem but there are several others; in an estuary it is normal for the range to increase with distance up the estuary while on an open coast time differences will often be experienced as High Water advances along the coast. All these problems can be eliminated if the tide gauge is located in the survey area - and if more than one gauge is used where the tidal regime

changes. Thus in Galveston either the Flagship Hotel or better still, a gauge at the end of the jetties should have been used in addition to Fort Point.


Government tide gauges in Galveston

A Fort Point
B Pier 21
C Flagship Hotel

Figure 2

The practical difficulty of this suggestion is that tide readings are required every half hour yet it may not be

feasible to leave a man at a location like the seaward end of the Jetties so that the gauge can be read. On the Gulf Coast, where the range is small, less frequent readings might be acceptable but a lot of time could be wasted taking the boat out to read the gauge, and, perhaps more significant, it is impossible to read the level accurately when the waves are three or more feet high. The answer to both these problems is a battery operated automatic gauge, either recording or with a radio link to a receiver and printer on shore or in the dredge. The latter is preferable for the dredge contractor as the dredge requires real time tide information while it is working. Such a gauge should be installed in a stilling well to eliminate the effects of wave action.

Data Processing. When sounding was done with hand lead and tag line, soundings were recorded 20 feet apart - the greatest density that could be plotted on a scale of 1/2400 - and it probably seemed acceptable that the early automated systems adopted by the Corps - 15 years ago - could only record depth once every 2 seconds, equivalent to 20 feet at a speed of 6 knots. The fallacy of this assumption is that many more false depths are generated by an echo sounder digitizer than by a hand lead - but with a separation of 20 feet the computer cannot distinguish the seabed from false echoes. This is the prime reason for the tedious hand editing phase that is necessary to remove 'spikes' from the data generated by these early systems; it is suspected that it may also be the reason why at least one Corps District no longer uses automated systems in its after-dredge surveys.

The solution is simple; the computer must be allowed to look at at least 5, and preferably 10, depths per second. If this is done false echoes may be detected and rejected with a high degree of reliability. The cross-sectional areas can be computed from slices 1 to 2 feet wide rather than 20 feet, giving a more accurate sum, while a high density of depths will reveal the 10 foot ridge left between passes of the dragheads that 20 foot samplings might miss completely. These observations, incidentally, apply whatever the size of the computer; a large mainframe in the District Office will produce less accurate results than a micro-processor in the boat if it has a lesser density of data to work with.

## CONCLUSION

Standard hydrographic survey techniques will tend to produce a chart and cross-sections that are too shoal - a result that favors the dredge contractor in the before-dredge survey stage but works to his disadvantage in the after-dredge phase. For this reason the contractors are investing in sophisticated computer systems and additional equipment of the type described in this paper in order to achieve precise after-dredge surveys. This will increase the risk of end-of-contract disputes and the Government's view may not prevail in court if the contractor can show that he has removed a source of error that the Government has ignored. On the other hand if the Government does not take advantage of the latest technology the contractor is being

given a present at the start of the contract - at the taxpayer's expense.

As always the objection of cost will be raised. The total cost of the equipment mentioned above - assuming the District already owns a survey boat, positioning system and depth sounder - is of the order of $100,000. Amortized over 5 years this becomes $20,000 per year, a trivial sum in relation to the value of a dredging contract and one that could not fail to be recovered in the course of the first contract.

# SESSION VI: REMOTE SENSING

DATA COLLECTION: REMOTE SENSING AND ITS INTERFACE WITH SURVEYING AND MAPPING

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## BIOGRAPHICAL SKETCH

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## ABSTRACT

The water resources mission of the Corps of Engineers (CE) requires the collection and analysis of large quantities of information. Remote sensing and survey and mapping technologies are one of many tools used to collect the required data. Each of these technologies has made tremendous technological advancements in the past decade which provide more accurate and cost effective methods. Many of these technological improvements go "hand in hand" in there development and compliment each other for improved data collection. These interrelationships and the impact on data collection will be discussed.

## BACKGROUND

The Corps of Engineers (CE), to successfully accomplish it's mission water resources management mission, requires the collection of engineering data for use in the planning, engineering, construction, and operational phases of the CE function. Data collection consist of many types of information about the environment in which projects are conducted. Both remote sensing and surveying and mapping are an integral part of the data collecting process and a keystone to the decision making process. Our mission requires data to contain what exists where, and when it was collected. Both remote sensing and surveying and mapping has contributed to answering these questions related to data collection and their roles is constantly evolving. The interrelationship between remote sensing and surveying and mapping has been close for many years both for technological advance and application.

## REMOTE SENSING

What is remote sensing? It is an all encompassing term that evolved in the late 1960's, referring to data collection without physical contact such as; aerial photography, laser, satellite, etc... A more technological definition for remote sensing is a process of collecting of collecting

observational data about a target without physical contact between the sensor and the target. Information is collected by measuring the electromagnetic radiation reflected or emitted by the target. Humans, with the eye and the brain, are still the most complex remote sensing system that exists. The eye is the sensor, with the body as the platform. The nerves are the transmitter for communications and the brain is the computer for data processing and information extraction.

Present technology consists of many types of sensors that detect more than the light visible to the human eye in various regions of the electromagnetic spectrum. The electromagnetic spectrum is all energy which travels in waves at the speed of light. This continuous spectrum of radiation has several discrete bands; the visible, infrared, and microwave bands are of a particular use in data collection, and instruments have been designed to detect electromagnetic radiation in different bands. A number of sensors, each sensitive to a specific band, may be grouped together to record data from the same target at the same time. Resolution is the minimum distance required between targets to distinguish them from each other.

Remote sensing is the result of growth in five fields; photography, aircraft, radiation physics, space technology, and computers. The development of remote sensing started with the first fixation of an image photograph in 1839. Aerial photography was well established by World War I and was used extensively for intelligence reconnaissance. By the 1950's, radar and thermal-infrared imagery had been developed. As man progressed from the balloon to aircraft and into space, remote sensing accompanied these platforms. The first systematic observations from space were made by weather observation satellite Tiros I, launched in 1960. The manned Mercury, Gemini, and Apollo missions produced quality terrain photographs. Apollo 9 and Skylab carried multi-spectral photography experiments, which were followed by a similar instrument on Landsat, the first permanent platform for gathering high quality earth resources data. Landsat I, originally called the Earth Resources Technology Satellite, was launched July 23, 1972, followed by Landsat II in 1975, Landsat III in 1978, Landsat IV in 1982, and Landsat V in 1984.

The world of remote sensing is rapidly expanding in the private sector and international arena. The role of the U.S. government, in remote sensing, is changing. In the past, the earth resources satellite program has been a government funded activity. This administration is in the process of transferring to the private sector, civil earth observing satellite systems. Legislation has been passed by Congress for commercialization and a contract is ready to be signed between the Department of Congress and EOSAT. On the international scene, the French, Japanese, Canada and East Germany are developing civil earth observation satellite programs.

## INTERRELATIONSHIPS

The remote sensor and the surveyor look at the same data but see different things. For example, the remote sensing specialist, when analyzing an areal photograph, interprets land-use, geology, soil type and cultural feature, where as, the surveyor or photogrammetist extracts topographic information. As the resolution of the photography has improved via, film types, optics, forward plane compensator each discipline is able to improve their analysis. Airborne lasers, which are becoming more prevalent in the surveying community, were first developed for remote sensing and are being explored for water quality information.

The French SPOT satellite system, to be launched in 1985, will provide imagery for remote sensing analysis but also will include the capability for topographic mapping at a coarse scale. Remote sensing needs survey technologies to provide the accurate location of the data. With remote sensing systems able to acquire data with more frequency, larger area and improve details, accurate survey data will be required.

## SUMMARY

The result of these expanding technologies has increased the quantity of information being collected, increasing our knowledge and ability to address broader concepts related to our engineering functions. Consequently, knowing more about our environment and, in larger aerial extent, increased the requirement for data and integration with computer models to analyze the data. The end result will be increased knowledge, better information, and better decisions. As the requirement for information increases and remote sensing technology advances, so will the requirement for surveying and mapping increase. These technological advances have forced the evolution of technical specialist and will require inter-disciplinary concept for decision making. With computers being able to handle more information to satisfy the expansion of our data requirements, so will the requirement of surveying and mapping data.

# NCD'S REMOTE SENSING APPLICATIONS TO SURVEYING AND MAPPING

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## ABSTRACT

The North Central Division (NCD) uses remote sensing in a number of applications to surveying and mapping and has the capability for more applications when the opportunity presents itself. Our five districts use, or have used, remote sensing techniques in land-based engineering surveys, topographic mapping, geographic information systems, flood plain delineation, reservoir area-capacity determinations and hydrographic surveys. The techniques used include microwave, laser and infrared distance measuring; aerial stereoscopic photo topography; comparative photogrammetry; radio triangulation positioning of hydrographic vessels; videotape inventorying of shoreline features; and sonar bathymetry. Several of these techniques use on-board data processing and display; others record the data on tape for later electronic processing.

The application of remote sensing techniques has greatly reduced the time and effort for surveying and mapping in NCD, while expanding several-fold the types and amount of data which are practicably usable.

## INTRODUCTION

The North Central Division has long used remote sensing in applications to surveying and mapping. In the broadest sense, remote sensing encompasses all observations from platforms and instruments removed by a distance from the objects or phenomena being measured or "sensed". It is important to remember this description since, in recent decades, many of the Corps' activities have been affected by techniques which previously had not been considered as remote sensing. This is particularly true of surveying, mapping and aerial photography - the areas being addressed by this conference. These activities now routinely use electronic ranging and positioning techniques in microwave, laser, sonar, video, and advanced airborne imaging systems. These systems must be included in any comprehensive assessment of the remote sensing usage by the Corps.

I was advised by one district surveyor that at least 95 percent of his topographic mapping is now done by aerial photography and the amount is constantly increasing, so that very little on-the-ground mapping survey is done anymore. The flood-plain cross sections, except that part actually in the water course, are all done from aerial photos. I am confident that other surveyors will confirm similar experiences.

For hydrographic surveys, automated hydrographic boats or launches are equipped with radio transponder positioning systems and sonar-type depth recorders in conjunction with on-board data recording or processing and plotting equipment.

Other end-products of our remote sensing efforts include overlays, annotated prints, photo mosaics, stereo photo prints, and input to various hydrologic models.

Before going through brief descriptions of some of the techniques used by our several districts, I would like to comment on recurring frustrations that are often heard while discussing this subject with them. Several district surveyors said that they are not using enough remote sensing applications. They explain that this is because there simply are not enough large multipurpose civil works projects underway. They have used some of the applications in past studies and have the capability to apply remote sensing techniques in a wide variety of situations to reduce the time and cost, while providing a superior product, for the planning, engineering and design of additional projects that are still needed. Projects in the future, whether authorized by Congress for Corps study and construction or secured through the Corps' work for others, may be on a smaller scale than the large multipurpose reservoir projects of the past. However, we may expect them to be more varied

and complex, requiring sophisticated analyses of environmental, economic and social conditions which can best be documented and quantified by remote sensing applications. Some examples would include providing assistance to EPA in the clean-up of hazardous or toxic substances and the oversight of waste treatment facility construction or assistance to Department of Energy (DOE) in the planning and construction of nuclear waste repositories or other DOE work. Work of these types, along with non-traditional water resource fields such as urban and regional water supply studies, will require intensified remote sensing with direct computer interfacing in future Corps surveying and mapping activities.

Getting back to the here and now, I will describe some ongoing activities in our districts.

## ENGINEERING SURVEYS

Automated surveying equipment is frequently used in the North Central Division for horizontal and vertical control surveys. HeNe laser, microwave and infrared light distance measuring instruments are used for traverses, centerlines and structure location. Recently, the Detroit District bought a new theodolite equipped with a portable data terminal for the collection, editing and storage of data and which can be interfaced with computer equipment.

## GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems are a relatively new development in engineering analysis. Maps generated from these systems serve as valuable analysis and management tools.

The Lake Erie Wastewater Management Study was initiated by the Buffalo District in 1974 with the primary objectives being to identify the major sources of non-point pollution in Lake Erie and to structure a plan to restore and maintain the lake's water quality. The Land Resources Information System (LRIS) was developed to quantify land resource characteristics and estimate the impact of land cover and management on non-point phosphorus sources. The LRIS data base is a variable-cell-size, multiparameter system which includes information on land cover and soils, with the data defined spatially by watershed and political boundaries. The data base is maintained in two principal forms: one suitable for making maps; the other for tabular summaries. The LRIS has not been used recently, due to lack of a suitable project. However, we still have this capability that could be put to use.

The Detroit District has been working with CRREL and NASA in a study aimed at using Landsat Multispectral Scanner data to study land use changes in the Saginaw River Basin. The data were classified into five categories. Maps of land use categories were aligned with U.S. Geological Survey quad maps. The study demonstrated that Landsat digital data can be placed into a geographic information system at low cost. The District has begun to develop an automated state-of-the-art system to handle storage, processing, analysis, and

display of these and other remotely-sensed image data. The District purchased a stand-alone processing system which is driven by a dedicated minicomputer. This image processing system will be the principal equipment base for processing satellite sensor, airborne scanner data and digitally-encoded aerial photography. The image processing system will provide in-house capabilities for generating repetitive input for basin-wide models such as for the Saginaw River. The system will be capable of generating high quality color slides, transparencies, and negatives for graphic arts and drafting applications.

The Rock Island District, with the assistance of CRREL, is proposing a remote sensing demonstration program for inland waterways. The major objectives of the program are: 1) to demonstrate the use of satellite and aerial images in water resources activities, including comparison of the two types of images as to information content, reliability, and cost of acquisition and analysis; and 2) to demonstrate the operational use of state-of-the-art hydrometeorological and environmental sensor data telemetered via the Geostationary Operational Environmental Satellite (GOES) data relay system.

Landsat Thematic Mapper (TM) digital satellite data will be used during the first phase of the satellite imagery program. The TM has new bands in the blue region, two in the middle infrared region and one in the thermal region to allow for increased spectral resolution, making it possible to differentiate more land cover and vegetation types. The 30-meter resolution of the TM sensor makes it possible to determine cover types for grid cells as small as 1.2 acres.

The second phase of the program will document the utility of the SPOT satellite digital data at 20-meter resolution in the multispectral mode for three spectral bands and at 10-meter resolution in the wideband black and white mode. The individual picture elements or pixels will be classified as to land use or cover type and placed into a gridded data base. Temporal analysis can be easily performed interactively on a computer to allow change over time to then be detected. Aggregation schemes will be built to run on the District's Harris computer to allow for easy transfer of pixel-by-pixel land cover classifications into a larger gridded data base system.

The locations of structures in the Corps floodplain areas can be integrated into the data base systems using aerial photographs and high-resolution digitizing equipment. Elevation and flood profile data can be simulated to show the extent of flooding and the depth to which the structures might be inundated.

The in-situ sensors will measure river stage, precipitation and other weather data that will be received by the District's GOES satellite downlink and processed on a dedicated Harris computer.

There are several benefits to using the satellite imagery and in-situ sensor data relayed via satellite. Computer-based storage and standardized interpretation packages will ensure that information is not lost, that it is available in an appropriate format, and that it will be integrated into the computer in such a way that it can be easily understood.

The results of the Remote Sensing Demonstration Program could be transferred to other districts throughout the Corps as the information becomes available, resulting in cost savings in the millions of dollars.

In a quite different approach to geographic information systems, the Buffalo District in 1978 initiated an extensive shoreline data inventory to update the Regulatory Permit Program files. Another objective was to find a way to detect, locate and describe shoreline structures, and to encode the data so they could be readily retrieved for use. It was expected that conventional aerial photography would be used. However, early in the study it was found that photo interpretation techniques were not effective as a sole or even principal means for identifying and describing shoreline structures. Therefore, a remote, low-altitude helicopter-based videotaping system was selected for the shoreline data inventory.

Videotapes were made from a helicopter by a television cameraman using a professional grade TV station "mini-cam". Variations in altitude and offshore distance were absorbed by a zoom lens, and all structures were reasonably centered and proportioned within the TV picture frame. Costs for the video tape averaged $25.00 per mile. The 20-minute oblique color tapes of the entire 4,000 mile shoreline were clear enough so that still photos of each structure could be produced. The data obtained in this way greatly reduced the need for field investigation of shoreline areas in response to permit applications, and it allows a permanent, computerized video disc record of the shoreline to be maintained.

The project has proven the feasibility of using videotaping procedures to develop a geographic information data base. These tapes have been of great value in many of the District's water resource activities, particularly in the analytical tasks associated with the processing of Department of the Army permits. Some of these tasks are the identification of structures, shoreline use and configuration, and wetlands. The videotapes are also used for existing structure verification, permit compliance, boat and dock counts, structure repair status, and verification of plans. Some other uses have been:

a. Federal project condition surveys

b. Surveys of shoreline damage caused by sudden storms

c. Studies of recreational boat harbor use, including congestion and safety problems

d. Authorized coastal and navigation studies

e. Identification of erosion-prone shorelines

f. Cooperative projects with state and other Federal agencies

g. A TV documentary on lake erosion problems and solutions produced by a local university

In summary, we have found that remote shoreline videotaping is by far the most economical and efficient data collection system for shoreline structure inventory, in effect bringing the entire navigable waters shoreline into the office.

## TOPOGRAPHICAL MAPPING

The application of controlled aerial photography for topographical mapping varies from year-to-year according to specific project requirements. Photogrammetric mapping is frequently required in all of our Districts for the preparation of topographic and planimetric project maps for channels and harbors, establishment of horizontal control grids, and for specific studies on flood control and beach erosion. These needs are normally handled contractually. Yearly expenditures have ranged up to $600,000 in a District.

In the Genesee River erosion study, aerial photos taken in 1938, 1954, 1963, 1974 and 1982 were used to map the river's centerline from Mt. Morris Dam downstream to Avon, New York, a distance of approximately 20 miles. Since these photos were taken at different scales, they had to be reduced to a common scale to plot the centerlines. The locations of the centerlines are being used to calibrate and verify a computer model that calculates the lateral movement of streams. This model will be used to determine the effects of Mt. Morris Dam on the lateral migration of the Genesee River. Future stream bank protection works will be studied using the model.

The Chicago District will be using aerial photogrammetry to map the Metropolitan Chicago area encompassed by the North Branch of the Chicago River flood protection project. The photogrammetric products will be used to categorize watersheds for the hydrographic models and to prepare final designs of the structures needed for flood protection.

The Detroit District is preparing design requirements for a completely automated mapping facility. This facility will likely include an analytical stereoplotter to use aerial photography for automated photointerpretation and photogrammetry. Over the next two years, the Detroit District plans to interface personal computers to the image processing system, to the proposed analytical stereoplotter, and to other computer systems to promote better information management within the District.

Rock Island District plans to use ETL's Global Positioning System (GPS) to establish or reestablish State Plane Coordinate System control along the Mississippi River for hydrographic surveys, recreational area mapping and

miscellaneous other surveys in that area. The existing baseline was established by the Corps in the 1930-1940 time period. It is believed that that line was intended to be of Second Order, Class II, accuracy and of the best precision attainable by the methods of technology then available. The GPS points will be tied to the recoverable remaining points of the existing survey baseline which follows one or both banks of the river for the entire 315-mile distance in the District. Coordinated control points will be set on one side of the river at about 10-mile intervals and at each Lock and Dam. It is expected that about fifty coordinated points will be set or recovered in the time frames of April-May or October-November, 1985. This work, which requires reimbursement to ETL, is expected to save about 25% (or $20,000) of Rock Island's control work each year, while improving the accuracy.

## FLOOD PLAIN DELINEATION

Remotely sensed data are used to both delineate the flood plain for various levels of flooding (such as the 100-year flood) and to document the extent of a flood event. This mapping of the extent of flooding has been valuable to the St. Paul District for use on the broad Red River of the North. Low altitude color IR has been used extensively for flood plain delineation along the Mississippi River and several other rivers and tributaries.

## RESERVOIR AREA-CAPACITY

Comparative photogrammetry of flood control reservoirs at several precisely-known elevations have been used to derive input for area-capacity data.

## HYDROGRAPHIC SURVEYS

NCD Districts have automated hydrographic survey launches to monitor conditions in the maintained channels within their jurisdiction. Some launch locations are provided by triangulation from radio transmitters at known location. These survey launches use various forms of digital sounding systems, and on-board data processing and storage equipment. Some of these launches can also provide limited on-board plotting capabilities for generating hydrographic maps.

The Detroit District has recently fielded two fully automated hydrographic survey systems which use multiple-sounder arrays to generate contour maps directly on-board. These "swath" sounding systems are deployed on barges and use multitransducer arrays. One barge is stationed at the Soo Area Office for surveys in the St. Marys River and environs and the other is assigned to the Detroit Project Office for surveys in the Detroit and St. Clair Rivers and other nearby maintained channels. Each system includes an array of 32 transducers to provide continuous bathymetric data over an approximate 120-foot swath. Data are recorded, processed and displayed on-board through dedicated microcomputer-based data processing equipment. Electronic positioning systems are used by these sweep sounding systems to provide horizontal control information for generation of maps and for on-board computations.

Unique features of the swath sounding systems include the capabilities to display hydrographic data on a monitor screen and to generate multi-color bottom maps on an on-board plotter. The colored bathymetric maps are plotted as the data are collected, with different colors assigned to various depth ranges. Since these systems provide total bottom coverage over a swath-width, they are used to locate channel obstructions to navigation. These systems, however, can also be used for studies on sediment transport, current patterns, and flow retardation problems.

## SUMMARY

The application of remote sensing techniques has greatly reduced the time and effort required for surveying and mapping in the North Central Division. At that same time, in conjunction with digitized imagery and computer processing, it has expanded several times over the amount of useable information and the number of ways and the ease in which the information can be used. All we need now are new tasks to use it on.

# SESSION VII: CONTROL

# THE NORTH AMERICAN DATUM OF 1983
# PROJECT STATUS

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## BIOGRAPHICAL SKETCH

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## ABSTRACT

The new adjustment of the North American Datum is nearing completion. All of the observational data in the National Geodetic Survey's archives associated with conventional horizontal control surveys have been placed into computer-readable form, and the task of verifying the correctness and cohesiveness of this huge volume of data is nearly complete. When the project is completed in December 1985, the results of the new adjustment will provide a highly accurate, continent-wide geodetic horizontal reference system of known accuracy, capable of meeting user needs for the foreseeable future.

## PROJECT STATUS

Introduction. The new adjustment of the North American Datum of 1983 (NAD 83) is now in its 10th year. This is the first general adjustment of the continent-wide horizontal geodetic reference system since 1927. In the decades since that adjustment, more than 200,000 control points have been added to the existing reference network. The result is a national position reference network which varies in accuracy from area to area and is in need of a major recomputation in order to provide today's users with the reliability and usefulness for which the network was originally designed.

The readjustment will place all of the national horizontal control network's surveying observations into a coherent reference system of known accuracy, suitable to meet user needs for the foreseeable future. The NAD 83 project will not only remove the distortions found in the

current geodetic network, but will also redefine the geodetic datum as a globally best-fitting position reference surface, replacing one which was based on North America alone. The Clarke Ellipsoid of 1866 will be replaced by one designated Geodetic Reference System of 1980 (GRS 1980), which resembles the size and shape of the Earth more closely, and whose origin is at the Earth's center of mass.

The readjustment project began in July 1974, and new NAD 83 coordinate values are expected to be available in December 1985. When it is completed, all of the observational data in the National Geodetic Survey's (NGS) archives associated with conventional horizontal control surveys will have been automated, verified, and subjected to the equivalent of a simultaneous least-squares adjustment. The final step in this process, the network adjustment itself, is one of the largest computing tasks ever attempted - the solution of a system of equations with approximately 500,000 unknowns, considering only the latitude and longitude unknowns of the network's 250,000 control points.

Automation of Archival Field Projects. All of the observational data in the NGS archives associated with conventional horizontal control surveys (horizontal directions, taped and electronically measured distances, and astronomic positions and azimuths) have been converted to computer-readable form in preparation for the new adjustment. This huge amount of data comprises between two and three million observations recorded in a total of more than 5,000 individual field survey projects. This process also included the related tasks of visually checking the keypunched field data for duplicate or missing observations, retrieving geographic positions and astronomic observations from the NGS data base to verify the field observations, and executing several computer programs which rigorously checked the completeness and correctness of the observational data.

Project-Level Validation. This first major element of the recomputation process comprised performing a minimally constrained least-squares adjustment on each of the more than 5,000 horizontal field survey projects contained in the NGS archives. In this phase of the readjustment project, the preliminary adjustment of each field project verified the mathematical consistency of the observations within the project. These least-squares adjustments held the position of one station fixed and included at least one distance and one geodetic azimuth to provide scale and orientation for the project.

Those involved in analyzing the adjustment results investigated missing observations, resolved observational blunders or errors in computing the NAD 27 positions which were used as preliminary positions for the NAD 83 adjustment, and rejected observations falling outside the limits defined by strict specifications. This labor-intensive phase of the NAD 83 project was completed in June 1982. The automation task, combined with project-level validation, encompassed more than 200 staff years of effort and included data from the more than 5,000 individual field projects performed by NGS and other Federal agencies, state and local government agencies, and private organizations, all of which contribute to the national horizontal network.

Block-Level Validation. The next step of the readjustment process is called block validation. In this step, the automated and provisionally adjusted observational data from the individual field projects are partitioned into blocks, each containing roughly the same volume of data. Here, data from all automated projects in a specific geographic area, or block, are combined with all the observational data already stored in the NGS data base for those stations located in that block, reformatted into one data module, and checked for completeness and consistency among projects observed in different years.

In block validation, scheduled for completion in February 1985, observations are cross-checked, duplicates are deleted, errors in preliminary positions are resolved, and geographic positions in the automated field data are compared to those in the NGS data base to ensure all stations have supporting observations. In addition, all directional observations at each occupied station are combined, and the resulting list is checked for incorrect and inconsistent spellings and large differences between different years' observations. This set of observational data is then matched against the positional data to resolve misidentifications.

The data in each block are then subjected to a least-squares adjustment to validate the mathematical consistency among data from different field projects. Any internal singularities (an insufficient number of observations to determine a point's position) or weaknesses are evaluated and resolved. Finally, the validated block of observational data is entered into the NGS data base, but not before a thorough check to make sure the data are consistent with that of neighboring blocks. To date, 765 of the total 843 blocks of data comprising the nationwide horizontal geodetic reference network have been processed. When the block validation phase is completed, all of the observational data making up the horizontal network will have been automated, verified for correctness and cohesiveness, and declared ready for the new adjustment of NAD.

Helmert Blocking. The Helmert blocking phase of the NAD 83 adjustment begins after the completion of the task we have called block-level validation. At this point all of the preliminary positions for the national network's horizontal control points and the observations comprising the network have been verified and entered into the NGS data base. The Helmert blocking software extracts from the data base chunks of the national network we call first-level Helmert blocks, each containing the positional and observational information for 1,500 network stations. Using all of the observational data associated with those stations located inside the block boundary, the software creates an equation system used to determine positions for the stations comprising that block. The size of these blocks and the locations of their boundaries are determined in part by the availability of computer resources, since a significant amount of core space is required to form and reorder the set of equations for networks of this size.

Adjusting the observations defining the nation's horizontal control network is a formidable data management task. The entire set of equations describing the latitudes and longitudes of the points comprising a large-scale geodetic network is not practical to fit into the memory of a computer. The Helmert blocking technique offers a solution in the following way: using this technique, a large problem is divided into several manageable sub-problems. The result is that by combining the separate solutions to the sub-problems, we obtain exactly the same result as if we were to solve the original problem in a single pass. For the Helmert blocking approach to the NAD 83 adjustment, the entire national network will be divided into approximately 160 computer-manageable sub-networks, each comprised of 1,500 to 2,000 stations.

The Helmert blocking strategy and its related software system offer NAD project managers a great deal of flexibility in allocating the personnel and computer resources needed for the readjustment project. The software system directing the Helmert blocking scheme operates completely automatically, in that once all first-level blocks are defined, the system proceeds as directed up the pyramid-like scheme of the Helmert blocking strategy creating its own job runs and job control language, and maintaining a list of activities already conducted and the results of those activities. The software system automatically calls for the particular magnetic tapes containing the set of equations for each block in the scheme and schedules each for the necessary operations in the computer's central processing unit. Approximately 700 tapes are required to store the entire set of equations.

This automation process allows NGS the freedom to use its personnel resources for other assignments needed for the publication of the new datum information. In fact, once the first-level Helmert blocks have been defined, only six to ten persons will be needed to direct the adjustment of the entire network. More importantly, the Helmert blocking strategy yields adjustment results identical to those of a simultaneous least-squares solution of the equations comprising the entire national network. Since a simultaneous solution is nearly impossible, even with all of the computer resources at our disposal, Helmert blocking or some similar strategy offers the only practical alternative in achieving the much-needed recomputation of the North American Datum. The Helmert block adjustment is expected to be completed in December 1985, 6 to 9 months after the completion of block validation.

Helmert Block Test. As a test of the Helmert blocking strategy, and also to meet the mapping requirements of the U.S. Geological Survey, NGS successfully adjusted all of the existing horizontal network control points in Alaska using the Helmert blocking software system. The adjustment was the largest that NGS has ever accomplished, resulting in a consistent set of preliminary NAD 83 coordinates for Alaska. More than 23,800 geodetic control stations (a total of 135,000 terrestrial and Doppler satellite observations) participated in the adjustment. This successful test of the

Helmert blocking strategy and software which directs it demonstrated their vital role in the upcoming adjustment of the entire continental geodetic control network.

Description/Recovery Note Analysis. One of the most important aspects of the readjustment project for the users of geodetic data is the correctness and completeness of the published geodetic data sheets. The NAD 83 task called description/recovery note analysis focuses on resolving missing or incorrect data elements for these data sheets which describe the location and condition of the more than 250,000 control points comprising the National Horizontal Control Network. This task is an extremely labor-intensive one, with extensive manual searches often needed to uncover discrepancies, duplicates, or voids in the descriptive information record for a given control point.

The data sheet contains a substantial amount of information for each network control point aside from the geodetic position, including the order and class of accuracy and the surveying method used to determine its position, a narrative description of how to reach the station, the title of the organization which established the station and the one which adjusted the data, the reference datum for the control point information, the "pack time" and mode of transportation used to reach the station, the type of monument used to permanently mark the control point, and the monument's magnetic property. In description/recovery note analysis, these data elements are checked to ensure they meet the specifications of the "Blue Book"--Input Formats and Specifications of the National Geodetic Survey Data Base, volume II, Horizontal Control Data. To date, descriptive information for more than 117,000 of the national network's 250,000 control points have been processed in support of the NAD 83 project. The projected completion date for this task is September 1986.

Publication of Adjustment Results. The publication of readjustment results will be done in two parts. The first will be the publication of an index listing of network station coordinates identified by both the station's name and a unique numerical station identifier. After the completion of the task called description/recovery note analysis, the complete geodetic data sheet will be published for all of the network stations which participated in the NAD 83 adjustment. The completion date for the first of these two steps is December 1985. Tentative plans call for network data in Alaska to be published first, followed by that in the Gulf Coast, the East Coast, the West Coast, the Great Lakes, and U.S. interior. Data for all network stations should be completed and published by September 1986.

Geodetic Data Sheet. One of the questions expressed by network users during the NAD 83 program has been: What will the horizontal control data sheet look like after the readjustment? Although the data elements comprising the new data sheet are arranged in a different manner, the user of geodetic data will have no difficulty in recognizing those items now seen on the familiar Horizontal Control Data Sheet.

Like the old form, the new data sheet will contain: station name; order and class of accuracy for the station and the surveying method (triangulation, traverse, etc.) used to determine its position; geodetic latitude and longitude; state plane coordinates (in meters); grid and geodetic azimuths to one or more azimuth mark(s) (from North); year established (and reestablished, if applicable); source number for the project in which the station's position is computed; and narrative description of the station's location, along with the directions and distances to the azimuth(s) and reference marks associated with the station.

The new form of the geodetic data sheet will contain all of the above information, plus the following elements useful for a large variety of geodetic data applications: accuracy of a station's latitude, longitude, and circular point accuracy; geoid height value; title of the organization (abbreviated) which established the station and the one which adjusted the data; adjusted height and the method used to determine the station's height; reference datum for the control point information; conversion values from NAD 27 to NAD 83; and in the description section, "pack time" and mode of transportation used to reach the station mark are explicitly stated. Both Universal Transverse Mercator coordinates and state plane coordinates are given for the point, with each being expressed in metric units. In addition, the new data sheet describes both the type of monument used to permanently mark the control point and the monument's magnetic property.

<u>NGS Assistance in Transferring Coordinates to NAD 83 Values.</u> In order to aid the surveying community in transforming current (NAD 27) geodetic coordinates to NAD 83 values, NGS will, as a public service, transform or assist in transforming coordinates based on any system (local rectangular, state plane coordinate, Universal Transverse Mercator (UTM), geodetic, etc.). In 1983 NGS issued a policy statement describing the assistance it will provide in converting coordinate values and the requirements for submitting data. The policy statement lists three methods for converting coordinate values, described in detail below, and states that the acceptability of the transformation method used will be determined on a case-by-case basis. The most important criterion for a rigorous coordinate conversion is the existence of a sufficient number of points in common between the system containing the submitted data and the National Geodetic Reference System (NGRS).

The first method outlined in the policy statement is a rigorous adjustment of original field surveying observations. In this procedure a requestor submits the original field observations and station descriptions to NGS for adjustment to NAD 83. The stipulations NGS must apply for this rigorous adjustment are that the survey points must be permanently monumented and described; the survey must have been performed to third-order, class I accuracy FGCC standards or better; the survey data must be connected by observations to national horizontal network points; and the observations and descriptions must be submitted in a prescribed format. This is the method NGS prefers, since it eliminates

distortions which may have been present in the NAD 27 network and ensures that new surveying data are included in NGRS. This method is also advantageous to those submitting data since NGS will perform a least-squares adjustment on the observations and publish the results.

The second method is a rigorous coordinate conversion that can be performed by NGS or the originator. It has been called the "approximate method", in contrast with the above, preferred "exact method" of adjusting the original field observations. The procedure for this "approximate" method is as follows: NAD 27 state plane, UTM, or local rectangular coordinates are converted from X and Y values to latitudes and longitudes; the NAD 27 latitudes and longitudes are converted to NAD 83 latitudes and longitudes using a least-squares transformation program such as LEFTI (available from NGS); and the NAD 83 latitudes and longitudes are converted to UTM or to state plane coordinates using the NAD 83 state plane coordinate system. The conditions which must be applied for this method are that the data must satisfy the established minimum requirement for using a least-squares transformation program: a minimum of four common points (the same physical point with coordinates in both reference systems) distributed uniformly throughout the area containing the coordinates; the coordinates must be submitted in a prescribed, computer-readable format; and the coordinates must be given in terms of geodetic (latitude and longitude), UTM, state plane, or local rectangular values. This method does not remove NAD 27 network distortions, and as a result, NGS will not publish the results.

The NGS policy statement also describes a third method, called a "simplified transformation", which involves averaging the shifts in latitude and longitude for an area containing stations with both NAD 27 and NAD 83 latitudes and longitudes. In this method the NAD 27 UTM or state plane coordinates are converted from X and Y to latitude and longitude values. Next the average latitude shift and average longitude shift for the area of the survey are used to convert the NAD 27 coordinates the NAD 83 values. The NAD 83 latitudes and longitudes are then converted to UTM or to state plane coordinate values using the NAD 83 state plane coordinate system. Since this third method uses only average coordinate shifts for a project area, the results will likely not be an accurate representation of the actual shifts at each station. As a result, NGS does not advocate using this method, and will provide only technical advice on its usefulness.

To summarize, NGS will provide the following assistance for converting NAD 27 coordinates to NAD 83 values:

- o Adjust original surveying observations and publish the results using method 1 if the stated requirements are met.
- o Convert coordinates using method 2 if the stated requirements are met.
- o Advise the originator on the usefulness of method 3.

In addition, NGS plans to cosponsor coordinate conversion workshops with the American Congress on Surveying and Mapping and to publish a technical report describing methods 2 and 3 in detail.

## CONCLUSION

The results of the NAD 83 project will represent, for the first time, the optimum accuracy obtainable from the millions of surveying observations which comprise the national horizontal control network. Furthermore, the new datum will represent a coherent positional reference system of known accuracy. To the surveyor using the NAD 83 published coordinates and related data, this means that surveying project closures can be evaluated without having to account for the constraints and distortions that the present network contains.

For example, in order to understand the closures they obtain, many users today must determine by one method or another the relative accuracies of adjacent portions of the network which were adjusted at different times. Since NAD 83 is a simultaneous recomputation of the entire nationwide system and will provide the accuracies required for nearly all anticipated applications, this practice can be eliminated. Moreover, the results of local surveys conducted before NAD 83 will remain valid as the basis for position and boundary determinations, engineering and mapping projects, and so on, all of which should be accepted by the courts.

The results of the NAD 83 project will also eliminate the frustrations a large number of surveyors have experienced when, using modern instruments and first-order procedures, they have often seen their survey results warped to second, or possibly even third-order accuracy when their data are adjusted to fit the constraints of the NAD 27 framework. The new datum readjustment will further restore user confidence in the national network, since NAD 83 means there will be fewer revisions of published coordinates resulting from area readjustments.

The improved national reference system will make it easier for a large number of local users to become advocates of the up-to-date national network and cease the practice of referencing their surveying data only to a local datum. To those surveyors just now entering the profession, the advantages of using the national network system will become even more pronounced. They will be able to use modern surveying technology with confidence, and without the skepticism of believing they must often apply disproportionate corrections to the resulting observations. The new datum will provide positional accuracies that will satisfy virtually any application, and it will provide these accuracies throughout the national network, not only in limited portions of the network, as is the case today. The entire spectrum of user groups will benefit from this unified, super-precise system of positional reference information capable of meeting the wide range of user needs for the foreseeable future.

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# NORTH AMERICAN VERTICAL DATUM (NAVD) UPDATE

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## BIOGRAPHICAL SKETCHES

David B. Zilkoski received a B.S. degree in forestry from the College of Environmental Science and Forestry, Syracuse, New York, in 1974, and a M.S. degree in geodetic science from the Ohio State University in 1979. He has been employed by the National Geodetic Survey (NGS) since 1974. From 1974 to 1981, as a member of the Horizontal Network Branch, he participated in the North American Datum readjustment project. In 1981, he transferred to the Vertical Network Branch, and currently serves as Chief, Vertical Analysis Section. Mr. Zilkoski is a member of ACSM, and is an instructor for the NGS Vertical Control Workshop and ACSM-NGS Surveying Instrumentation and Coordinate Computation Workshops. He is also a member of AGU and IAG Special Study Group 4.96, "Models for Time-Dependent Geodetic Positioning."

Gary M. Young is Acting Chief, Vertical Network Branch, National Geodetic Survey. He received a B.S. degree in mathematics from Virginia Polytechnic Institute and State University in 1965. In 1970, he received a M.S. degree in engineering, with a specialization in geodesy, from Purdue University. Since 1965, he has been with the National Ocean Service's National Geodetic Survey (formerly the U.S. Coast and Geodetic Survey). He first served as a geodesist and later as New Datum Coordinator of the North American Datum readjustment project in NGS' Horizontal Network Branch. Beginning in 1978, he became Assistant Chief of the Vertical Network Branch. He is a member of ACSM and AGU.

## ABSTRACT

This report provides a brief history of the vertical control portion of the National Geodetic Reference System (NGRS) and presents an update of the progress by the National Geodetic Survey on the North American Vertical Datum of 1988 (NAVD 88) readjustment project. This project, scheduled for completion in 1988, has dominated Vertical Network Branch activities since the project received approval and funding, beginning in fiscal year (FY) 1978. The total project includes several production and research efforts. The most important of these are described in this report.

## BACKGROUND

The first leveling route in the United States that can be considered to be of geodetic quality was performed in 1856-57 under the direction of G. B. Vose, U.S. Coast Survey (now called the National Ocean Service). The leveling survey was required to support currents and tides studies in the New York Bay and Hudson River areas. The first leveling line that was officially designated "geodesic leveling" by the Coast and Geodetic Survey followed an arc of triangulation along the 39th parallel. This leveling survey began in 1887, at bench mark A in Hagerstown, Maryland.

By 1900, the vertical control network had grown to 21,095 km of leveling that could be considered "geodetic". These data included work performed by the Coast and Geodetic Survey, various components of the Corps of Engineers, the U.S. Geological Survey, and the Pennsylvania Railroad. A "mean sea level" reference surface was determined in 1900 by holding elevations fixed at five tide stations. Two other tide stations participated indirectly. Subsequent readjustments of the leveling network were performed by the Coast and Geodetic Survey in 1903 (a total of 31,789 km of leveling; eight tide stations were used); 1907 (a total of 38,359 km of leveling; eight tide stations were used); and 1912 (46,462 km of leveling, nine tide stations were used) (Berry, 1976).

The next general adjustment of the vertical control network did not occur until 1929. By then the international nature of geodetic networks was well understood and Canada provided its first-order vertical network which was combined with the U.S. net. The U.S. network had grown to 75,159 km of leveling. Canada provided an additional 31,565 km. The two networks were connected at 24 vertical control points (bench marks) that extended from Maine/New Brunswick to Washington/British Columbia. Mean sea level was held fixed at 21 tide stations in the United States and five in Canada. Although Canada did not adopt the "Sea Level Datum of 1929" determined by the United States, Canadian - U.S. cooperation in the general readjustment strengthened both networks.

## INACCURACIES INTRODUCED IN THE 1929 DATUM RESULTS

At the time of the 1929 General Adjustment it was known that local mean sea level at the various tide stations held fixed (at 0.0 elevation) during the adjustment could not, in reality, be considered to be on the same equipotential surface. This is due to the so-called sea-surface topography effect, currents, water temperature and salinity, barometric pressure, etc. It was thought at that time, however, that the errors introduced by this approach were not significant, being of the same order of magnitude of terrestrial leveling observational errors. We now know that significant errors were introduced into the 1929 General Adjustment by considering each of the tide stations to be on the same equipotential surface. The error is estimated to be as much as 0.7 m from coast to coast.

Recognition of this distortion, and confusion concerning the proper definition of local mean sea level resulted, in 1976, in a change in designation of the official height system from "Sea Level Datum of 1929" to "National Geodetic Vertical Datum of 1929" (NGVD 29) (Federal Register, 1976). The change was in name only; the same geodetic height system continues from 1929 to the present.

There are several other distortions in the present NGVD 29 system. Some will be discussed later in this report.

## READJUSTMENT OF THE NORTH AMERICAN VERTICAL DATUM OF 1988

Approximately 625,000 km of leveling have been added to NGRS since the 1929 adjustment. In the intervening years, numerous discussions were held to determine the proper time for the inevitable new General Adjustment. In the early 1970's, NGS conducted an extensive inventory of the vertical control network. The inventory identified thousands of bench marks that had been destroyed, due primarily to post-World War II highway construction, as well as other causes. Many existing bench marks had become unusable due to crustal motion associated with earthquake activity, post-glacial rebound (uplift), and subsidence caused by the withdrawal of underground liquids. Other problems were caused by forcing the 625,000 km of leveling to fit previously determined NAVD 29 height values. These distortions, amounting to as much as 9 m, are itemized in Table 1:

| Source of Distortion | Approximate Amount (Meters) |
|---|---|
| Patching 625K Km to Old 75K Km Net | 0.3 |
| Constraining Tide Gage Heights in NGVD 29 | 0.7 |
| Ignoring True Gravity in NGVD 29 | 1.5 |
| Refraction Errors | 2.0 |
| Post-Glacial Uplift; Minnesota, Wisconsin, Etc. | 0.6 |
| Subsidence From Withdrawal of Fluids | 9.0 |
| Crustal Motions From Earthquakes | 2.0 |
| Bench Mark Frost Heave | 0.5 |

Table 1. Distortions in Present NGVD 29 System.

In 1973, the "Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying," Office of Management and Budget (1973), stated, in part:

"The fundamental geodetic networks have become incomplete through obsolescence and need new surveys and a National Adjustment to meet modern demands... based on our requirements study, we conclude the vertical control program is falling short of meeting national needs, and, therefore, must be expanded... We recommend doubling the National vertical control program."

A position paper, prepared by the National Geodetic Survey (NGS), soon followed, specifying the tasks and amount of effort required to modernize the vertical control network (National Ocean Survey, 1976). In 1978, the National Research Council's National Academy of Science's Committee on Geodesy (1978) stated in "Geodesy: Trends and Prospects":

"We recommend that the computations and additional observations for the new adjustments of the North American Horizontal and Vertical Control Networks by the National Geodetic Survey be given the support necessary to bring about their completion in an orderly way."

"We endorse for scientific, as well as practical reasons, the adjustment of the North American vertical control network..."

"The committee endorses the efforts of the National Geodetic Survey to systematize, update and adjust the national horizontal and vertical control networks... these data constitute a valuable framework for decades to come."

NGS prepared a budgetary initiative for fiscal year 1977 to finance this project. The initiative was not approved. A revised plan was later approved and the General Adjustment program formally began at the beginning of FY 1978. The program called for the completion of several tasks. These tasks will be discussed in more detail later in this report.

## INTERNATIONAL COOPERATION

Early in 1982, Canada and the United States reached agreement on many of their cooperative efforts for the new adjustment and signed a formal Memorandum of Understanding concerning the NAVD 88 readjustment project. The agreement, which was signed by officials of the Canadian Surveys and Mapping Branch and the U.S. National Oceanic and Atmospheric Administration, stated:

"Adoption of a Common North American Vertical Datum (NAVD 88)

Purpose and Participants

The National Oceanic and Atmospheric Administration, an agency of the Government of the United States of America, and the Surveys and Mapping Branch, an agency of the Government of Canada (hereinafter the "parties"), both having responsibilities in the geodetic field and both desirous of ensuring the adoption and implementation of a common geodetic vertical datum by the two agencies, agree as follows:

1. The parties agree to cooperate in the 1988 North American Vertical Datum (NAVD 88) project and work toward its completion by the end of 1988.

2. The parties agree to coordinate and share research and development related to the project.

3. The same reference surface, as near the geoid as practicable, will be used by both parties as the common datum.

4. The practical or technical realization of a common NAVD will be defined by both parties and will be determined and adopted in a mutually agreeable manner.

5. Both parties agree to adopt the same system of heights and to use compatible mathematical models of corrections to account for systematic errors in the observation of height differences and compatible procedures to incorporate tidal, gravitational, and atmospheric loading effects.

6. For the common adjustment, both parties agree to provide potential differences, based on observed gravity and elevation differences, corrected for systematic error.

7. The parties will agree on the "border junction points" to be used in the adjustment and will confer on the other details associated with the adjustment. For this purpose, their representatives shall meet at least once each year until the completion of the project.

8. The parties agree to utilize NAVD 88 upon completion of the project or as soon as practical thereafter.

9. The rate at which new maps and charts will incorporate NAVD 88 will vary between the parties and will be determined in each case by practical and economic considerations.

10. Costs incurred under this agreement shall be borne by the party incurring such costs.

11. It is understood that the ability of the parties to implement this agreement is subject to the availability of appropriated funds.

12. This agreement may be amended at any time by the mutual consent of the parties concerned.

13. This agreement will become effective upon the signature of both parties and will remain in effect until terminated by mutual agreement or upon 30 days written notice by either party to the other.

14. Nothing herein is intended to conflict with respective laws and regulations applicable to each of the parties. If the terms of this agreement are found inconsistent with existing regulations or law applicable to each of the parties, then those portions of the agreement which are determined to be inconsistent shall be invalid, but the remaining terms and conditions of this agreement not affected by any inconsistencies, shall remain in full force and effect."

Similar cooperation will lead to the incorporation of leveling data from Mexico and the Central American countries, making the new vertical datum a truly international one. As reported in the Federal Register (1983), the designation of the new reference for the vertical control network will be the "North American Vertical Datum of 1988," which will also be referred to as "NAVD of 1988" and "NAVD 88," to acknowledge the international scope of the cooperation in the project, and the consistency of the results. The improved geodetic heights are scheduled for distribution in 1989.

## TASKS REQUIRED BY THE NAVD 88 READJUSTMENT PROJECT

Conversion of Data (Descriptive and Archival Observational Leveling Data) to Computer-Readable Form. The first major NAVD task to be completed was the conversion to computer-readable form of descriptive data (bench mark descriptions) from paper copy (primarily field records) under the direction of NGS' National Geodetic Information

Branch personnel. In early 1975, NGS applied for and received 1 year of funding under an amendment to the Public Works and Economic Development Act of 1965. The legislation required the funds be spent in an area of high unemployment. Detroit, Michigan, was selected as the potential contract site and the Department of Commerce solicited bids on the project. By January 1976, the contract was awarded.

Preliminary NGS preparation included finalizing formats, preparing conversion instructions, and selecting an on-site technical representative. Descriptions were organized into areas based upon their geographic location within blocks of 1-by-2 degrees of latitude and longitude. The descriptions were sequenced by line numbers in the order desired for publication, updated with recent recovery reports, edited for data omissions or obvious errors, and assigned unique identifiers (designated archival cross reference numbers). This identifier was to serve as the link between bench mark data stored in various computer files.

Acceptable error rates were stipulated to be less than 0.3 percent per data set. All data were key-verified and copied to magnetic tape by contract personnel for shipment to NGS. Agency personnel proofread a sample of submitted data sets. Software was developed to read each data set and check for format errors or data omissions. Despite lost data shipments, a parcel delivery service strike, and tornado damage to the contractor's plant, this contract was successfully completed in March 1977 with a minimum of data-set rejections.

Approximately 60 percent of the active descriptions contained in agency files were automated at a cost of $330,000. In October 1977, a similar contract was awarded to a Rockville, Maryland, firm. Work proceeded smoothly, and by January 1980, the entire file had been automated. A total of 457,000 bench mark descriptions had been automated over the 4-year period at an approximate contract cost of $600,000.

Today all new bench mark descriptions and recovery notes are automated by NGS field personnel as standard operating procedure for new field projects. This information is merged into existing files with software programmed to adhere to specifications as stated in theFederal Geodetic Control Committee's publication "Input Formats and Specifications of the National Geodetic Survey Data Base, Volume II: Vertical Control Data," commonly referred to as the Blue Book. The descriptions reside on five off-line disk packs and can be retrieved by archival cross reference number, state, quadrangle, or county.

The second major task to be completed for the NAVD project was the conversion of archival (historic) observational leveling data to computer-readable form (Till, 1983). In 1975 NGS began retrieving all its original leveling records held in the National Archives and the Washington Federal Records Center. Because of the large volume of data (approximately 50,000 field books), it was necessary to acquire the data over a period of several years. The retrieval of data was accomplished on a state-by-state basis, following the manner in which the data were stored in the archives. Because this undertaking involved a large volume of data, it was decided that instead of keying individual leveling-rod readings, as is presently done with new NGS surveys, only the stadia intervals, section elevation difference, date, time, "sun code," "wind code," temperature, and number of setups would be converted to computer-readable form.

This conversion was initiated using personnel of the Vertical Projects Section, Vertical Network Branch (VNB). After a period of 1 year, it was decided that these personnel would not be able to convert the observations within the time frame set for the readjustment. Subsequently, in July 1976, a private contract was awarded to convert and validate the archival leveling data. In April 1978, this contract was replaced by one which was responsible for key punching only. (It was learned from the original contract that data validation was best accomplished by NGS.) Beginning with the second contractor, the VNB provided direct technical supervision of the conversion to computer-readable form, and was solely responsible for the validation and review processes. This proved to be very successful. In January 1982, the conversion of all NGS archival observational leveling data to computer-readable form was completed.

The data were processed through a series of computer programs which included "range" checks on individual data fields to ensure the data were "reasonable." Verification of the leveling observations was accomplished by computer recomputation of the leveling lines. The resulting computations were compared against abstracts of the original field computations. Comparisons between individual section lengths and between individual section elevation differences were two of many checks the programs accomplished. The programs also indicated excessive corrections for instrument collimation. When a leveling line was double run, additional comparisons were made. The editing, validation, and review of all archival leveling data were completed in November 1982.

Geographic Positions for Bench Marks. In order to provide automated retrieval capability and apply position-dependent corrections to the observations, a geographic position (latitude, longitude) has been determined for each of the 515,000 bench marks. For those monuments not part of the horizontal control network, the effort involved plotting bench marks on appropriate maps (using the descriptive data mentioned previously) and then determining a "scaled" position using digitizing equipment. This task, which began in 1975, and completed in May 1984, involved a joint effort of personnel from the Vertical Network Branch, Operations Branch, National Geodetic Information Branch, and the Pacific Marine Center of NOS. Approximately 100,000 of these geographic positions were determined under contract to a private firm in Long Beach, California.

Releveling in Support of the NAVD 88. An important feature of the NAVD 88 program is the releveling of much of the first-order vertical control network in the United States. The dynamic nature of the vertical control network requires a framework of newly observed elevation differences in order to obtain realistic contemporary height values from the readjustment. To accomplish this, NGS has identified 83,000 km of the network for releveling. Replacement of disturbed or destroyed monuments precedes the actual leveling. This effort also includes the establishment of highly stable "deep-rod" bench marks, which will provide reference points for future "traditional" or "satellite" leveling systems. Field leveling is being accomplished to first-order, class II specifications, using the "double-simultaneous" method. An increase in leveling progress (while maintaining acceptable accuracy) has been accomplished by equipping NGS field leveling units with specially modified subcompact trucks for rodmen as well as observers. This form of "motorized" leveling has increased production by at least 20 percent as compared to former leveling procedures. Alternate approaches, including high-accuracy trigonometric leveling, are also

being evaluated (Whalen, 1984a). To date, 56,000 km of leveling progress have been accomplished. Completion of field leveling is scheduled for September 1987. Older data which are consistent with the newly observed data will be included in the final framework for the readjustment.

Preparation of New Leveling. This activity, being performed in the Geodetic Leveling Section, VNB, processes both NGS and non-NGS new leveling projects. The proposed goal is to process 106,000 km of new leveling by September 1986. The tasks consist of validating data files, applying appropriate corrections, and loading the data into the Vertical Data Base (Balazs, 1984). As of December 1984, 79,000 km of leveling have been processed (75 percent complete).

REDUC4 Processing. This procedure consists of converting files from "Blue Book" format (Koepsell and Ward, 1984) to the vertical observation library file format, checking the fields for valid entries, calculating and applying corrections to leveling observations, and loading data into the VNB Data Base. The National Geodetic Vertical Control Network consists of 16,000 leveling lines. The current goal is to process all data lines through the REDUC4 program by March 1985. As of December 1984, 15,666 leveling lines have been processed.

Block Validation. Block validation is a process where all observed elevation differences in a predefined area are combined together and analyzed. There are many steps performed during block validation. During the analysis, a first-order primary network, consisting of the latest data, is selected, analyzed, and documented. Appropriate remaining leveling data are then incorporated into the first-order network. Leveling lines which do not fit (statistically) with the network will not be included in the primary network and will be documented in the report. During the analysis, profiles, loop closures (primary and secondary), section misclosures, date of data, survey order and class, bench mark stability, previous adjustment reports, and past studies are all utilized to make decisions about the data.

As of December 1984, 129,000 bench marks have been processed. The current goal is to process all bench marks by September 1987.

Magnetic Error Modeling. Approximately 50,000 km of NGS leveling lines were observed with compensator-type leveling instruments. It was recently determined that the "horizontal" line of sight of compensator (automatic) leveling instruments was influenced by magnetic fields (Rumpf and Meurish, 1981). Professor Rumpf, invited to join forces with NGS, and Charles Whalen, then Chief of VNB, now retired, designed a magnetic calibration facility at NGS' Instrumentation and Equipment Section located in Fredericksburg, Virginia (Whalen, 1984b). All NGS compensator leveling instruments have been calibrated at this facility. The influence of d.c.-induced magnetic fields (e.g., the Earth's magnetic field) on NGS compensator leveling instruments is now well understood. The task remaining to be completed is to develop a magnetic model which will calculate the appropriate correction to be applied to the data.

This task includes: (1) identifying factors which cause compensator leveling instruments to deviate from the calibrations performed in the laboratory; (2) estimating the corrections independent of the calibrations, e.g., through profiles and adjustment; (3) estimating factors for instruments which cannot be calibrated; and (4) developing and implementing a procedure to check and apply the correction.

The VNB has identified all leveling lines which were observed using compensator leveling instruments. Magnetic corrections, computed from calibration data, have been applied to a few leveling lines. Profiles were prepared comparing both corrected and uncorrected values to previous leveling data. It appears that the correction is over-correcting some of the lines. NGS' Geodetic Research and Development Laboratory (GRDL) is currently studying magnetic error. The study should be completed in time to finish the REDUC4 processing by March 1985.

Appropriate A Priori Estimates of Standard Errors. When different types of data are combined and adjusted, it is essential to impose a correct relative weighting scheme. This means that a priori standard errors of observations must be estimated for each group of data. This task includes identifying the different groups of leveling observations, and establishing and implementing a procedure to determine the appropriate a priori standard error of observations in each group.

Groups of data (according to instrumentation, field procedures, etc.) have been identified but may be modified after additional analysis. Different methods for estimating variance components in least-square adjustments are being considered. The Iterative Almost Unbiased Estimation (IAUE) technique (Lucas, 1984) has been implemented on NGS' HP1000 minicomputer. Other analysis include: (1) comparing old and new section and loop statistics, (2) profiles, and (3) formal error studies of past field techniques.

Water-Level Transfers and Tidal Information. This task includes defining the data formats for water-level transfer and tidal data, loading the data, and estimating their observational accuracies.

The 1977-83 water-level transfers and current primary National Tidal Observation Network tidal data (monthly means) have been keyed and placed in computer-readable form by the Tides and Water Level Branch, Office of Oceanography and Marine Services. The data need to be reformatted and placed in the Vertical Network Data Base. Studies have been performed which estimated the accuracies of these data (Stoughton, 1980). Additional analysis will be needed to determine how they should be weighted in the NAVD final adjustment.

Interpolate Gravity Values for Bench Marks. The NAVD readjustment will be performed using geopotential numbers. This requires estimating gravity values for all bench marks involved in the readjustment. Phase 1 of this task consists of interpolating gravity values and their corresponding estimates of accuracy for all bench marks in the Vertical Synoptic file. The last of the gravity values will be loaded by April 1985.

The second phase of this task is to perform a study to determine if all gravity values are accurate enough for NAVD 88 purposes. A procedure will be developed which examines elevation differences, and determines if the gravity value estimates are accurate enough. If additional gravity values are required, then an observation plan for an area will be developed and implemented. It is not anticipated that many areas of the country will need additional observations.

Development of NAVD Software. The Vertical Network Branch has identified that 3 staff-years of software development effort is required in support of the NAVD 88 project. The programs are needed to increase productivity without sacrificing quality. They mostly include

graphics routines; some management tools have also been identified. Some examples of the programs include plotting profiles, junction details, loops, residuals, and networks. Having graphics capabilities is extremely important to the timely success of the project. The specifications and algorithms for each program need to be documented. Then they will need to be coded, debugged, and implemented.

In addition to the programs mentioned previously, the programs to perform the Helmert blocking process need to be designed, coded, debugged, and implemented. VNB is currently studying all programs involved with the NAD 83 Helmert blocking system. A majority of the programs can be utilized as they exist today. However, programs that create or modify lowest-level Helmert blocks will have to be rewritten because they are specific to horizontal data. A detailed analysis of these programs needs to be performed and the impact should be considered in any future purchase of a VNB minicomputer.

NAVD 88 Crustal Movement Studies and Procedures. This task includes identifying areas of the network which are influenced by crustal motion, and establishing and implementing a procedure to account for these movements.

During the past few years, VNB has been analyzing different numerical techniques in an attempt to model crustal movement. This would enable the NAVD 88 project to include most data and bench marks in one adjustment. The studies, performed mainly in the Houston-Galveston, Texas, area have been successful in identifying the data required to model movements precisely. The lack of required geologic and hydrologic information, along with inadequate network design, makes modeling many areas for precise movements very questionable.

Areas of the networks most likely influenced by crustal movement are fairly obvious, e.g., California, Texas Coast, sections along the East coast, and sections of the U.S. Northern border. Other areas will be identified as block validation continues and additional research material is obtained. It may be possible to modify some observations for crustal motion effects, but it is more likely that most areas will be constrained to the framework network surrounding the area in question. A plan defining the technique to be implemented in these "moving" areas will be developed and documented.

A plan defining the technique to be implemented in California has been developed and documented. The plan includes defining a primary network in California which is consistent within itself, and then making modifications to accommodate crustal motion.

Framework Adjustments. This task will include designing and analyzing framework networks (regional and national). The analysis will be helpful in determining the effects of various datum constraints, magnitudes of height changes from the NGVD 29 datum, influences of systematic errors, deficiencies in network design, and additional releveling requirements.

A plan of action will be developed and documented. Studies comparing local mean sea level to geodetic leveling along the East and West coasts are currently being performed (Zilkoski, 1984). In the past, a major analysis was performed in the Gulf Coast region from Texas to Florida. The entire set of leveling observations will be processed through program REDUC4 by March 1985. At that time, all areas of the

country can be analyzed for network deficiencies and the releveling schedule can be made more optimum.

Data Base Design, Entry, and Retrieval. This task includes defining data elements and developing routines to load, edit, and retrieve data from the NGS integrated data base (IDB). The VNB and Systems Development Branch are working together on a systems analysis study of all VNB activities. This will help in identifying all data elements needed for IDB. Once IDB is operational, routines will need to be developed to load, edit, and retrieve data from IDB.

GPS and NAVD 88. GPS-derived heights cannot be used, as is, as observations in the NAVD readjustment project, however height differences and geoid undulation differences should be helpful in detecting and providing an upper limit on systematic errors in leveling data and for strengthening the network.

The VNB is working with NGS' Astronomy and Space Geodesy Section, on a study to estimate geoid slopes using GPS and differential leveling (Hothem, Fury, and Zilkoski; 1984). This is a start, but a comprehensive plan of action must be developed to look at what GPS offers the NAVD 88 project.

Studies have been performed estimating orthometric heights using GPS and gravity (Engelis, Rapp, and Bock; 1984) and estimating subsidence using GPS-derived heights (Strange, 1984). GRDL is currently looking into what GPS offers the NAVD 88 project.

Datum Definition. Datum definition is one of the last tasks which will be performed in the NAVD 88 project. There are many factors which need to be considered before a decision can be made. It may be as simple as fixing the height of a tidal bench mark and performing a block shift to minimize differences between NAVD 88 heights and the latest Local Mean Sea Level epoch heights. However, there are still some unanswered questions: How do we incorporate and weight tidal heights and water-level transfers? Can we estimate the effects of sea surface topography (SST) at tidal stations? Can satellite information help control datum distortions?

These tasks are currently being looked at; we are developing and documenting a specific plan of action.

Helmert Blocking. This task consists of partitioning 1.5 million unknowns and associated observations into manageable blocks and solving a least-squares adjustment of the entire data set.

The blocking strategy of NAVD will be easier to define than for other large adjustments such as the North American Datum (NAD) readjustment (McKay and Vogel, 1984). After the first-level blocks, it is anticipated that 90 percent of the unknowns will be "interior". A blocking strategy needs to be developed which includes boundaries and the unknowns that are to be carried to the higher levels. The Helmert blocking technique for adjustment of data has been documented by others (Dillinger, 1978; Isner, 1978; Wolf, 1978).

Exchange of Data with Canada, Mexico, and Central America. This task includes identifying junction stations and associated information, along with their formats, which will be required at the countries' borders for the final solution. The corrections and methods of applying corrections will also be addressed. There is time before the

junction stations are actually needed, but meetings should be held to establish preliminary formats and to determine the procedures which will be used to apply the corrections, as well as which corrections are going to be applied.

Publication. This task includes reviewing descriptions on a random basis, and publishing final adjustment heights in 30 minute quads. However, it is planned to have NAVD 88 adjusted heights available to the public immediately following the adjustment. They will be loaded into NGS' IDB and the public will be able to access the IDB directly. It is hoped that most people will access the NGS IDB when requesting data. With the price of computers decreasing and their sophistication increasing, this is not an unrealistic goal. In any event, they will also be available in hard copy and microform, at a higher cost.

Progress and Final Reports. Detailed progress reports addressing each task and their status are prepared every 6 months.

The final report is not scheduled for completion until September 1989. This report will give the history of the network and readjustment project; technical decisions made about weights imposed, observations used, adjustment technique, and crustal motion information. Previously published reports will be the main source for the final report.

## CONCLUSIONS

It is obvious that the NAVD 88 project requires an enormous amount of effort. The project, scheduled for completion in 1988, has dominated Vertical Network Branch activities since the project received approval and funding, beginning in FY 1978. The production and research efforts are on schedule.

The benefits of NAVD 88 make this effort worthwhile. A vertical control network containing a consistent, accurate set of adjusted heights has been needed for a long time. Other products and services resulting from the project will be used by people for a long time to come. For example, the observed elevation differences which are now in computer-readable form, are available for future crustal motion studies and regional readjustments. The real benefits will become apparent when the multitude of users start using the results of the new adjustment.

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# VERTICALLY STABLE BENCHMARKS: A SYNTHESIS OF EXISTING INFORMATION

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## BIOGRAPHICAL SKETCH

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## ABSTRACT

Techniques used for topographic, hydrographic and structural movement surveys are no more accurate than the benchmarks used as reference. In northern areas, frost action can cause substantial vertical movement of benchmarks. Benchmarks can also subside or shift in wetland and coastal areas. Various benchmark designs and installation procedures reduce or eliminate movement, but information on the designs and procedures is widely scattered and not available to Corps of Engineers (COE) Districts in one report. This paper gives the preliminary results of a synthesis of existing information compiled from surveys of Corps of Engineers Districts and Divisions, U.S. and Canadian government agencies and private industry and from a literature review. A matrix for selecting benchmarks appropriate for various climatic and soil conditions will be prepared from the synthesized information. This matrix and a description of the procedures required for installing various types of benchmarks will be available in September 1985.

## INTRODUCTION

Techniques used for monitoring crustal deformations (Wyatt et al. 1979), hydrographic surveys, surveys of the movement of structures (Gupta et al. 1973) and any leveling surveys are no more accurate than the benchmarks used as reference. In the northern contiguous states and Alaska, frost action can cause benchmarks to be substantially uplifted. In temperate regions, benchmarks can be uplifted, subside or shift in wetland and coastal areas or where soils are

expandable and unstable. Information on benchmark designs and installation procedures in areas where benchmark stability is a problem is available but it's widely scattered in many reports. The purpose of this report is to present some preliminary findings of a synthesis of this information. This is part of a Corps-funded project designed to prepare a matrix that can be used by Corps' surveyors to select benchmarks appropriate for different climatic and soil conditions. In addition, Slater and Slater (1979) and Floyd (1978) point out that benchmark design and installation procedures are virtually unchanged in the last 20 years, yet survey instrument precision has substantially improved. The information available from this project may be useful in determining if improved benchmark designs and installation techniques are required to ensure appropriate accuracy of surveys performed with these improved instruments.

Additional information will be provided in the final project report, which will be based on an analysis of all input from Corps of Engineers Districts. This report is based on a synthesis of some of the Districts' input.

## APPROACH

Information on methods for eliminating or reducing vertical movement in survey benchmarks was compiled from the Corps of Engineers, other government agencies, private industry and the open literature (Table 1). Corps' District input was obtained via phone conversations and a questionnaire with seven questions about the purposes for which benchmarks are required, types used for each purpose, lateral and vertical stability requirements, problem conditions within each District, pre-installation site characterization, steps for installing benchmarks, and costs. Input from other agencies and private industry was obtained by phone, letter reports and unpublished reports. Four literature data bases (Georef, Compendex, NTIS, Engineering Index) were searched and all open literature available as of December 1984 was reviewed for this report.

## BENCHMARK STABILITY PROBLEMS

There are many types of reference datums and benchmarks. Each has been used acco ding to the accuracy requirements of surveys. Some are as simple as fire hydrants, manholes, nails in trees or fenceposts, and pins in stone or concrete steps, house foundations or platforms. Usually these are unsatisfactory for precise references for repetitive long-term (annual) surveys. Somewhat more stable references include pins installed in bedrock, in large concrete foundations resting on stable soil and in piles driven to bedrock or refusal. However, even these can shift or move vertically. A permanent, very stable benchmark must not be

affected by human or natural disturbances (Bozozuk et al. 1963).

Some of the sources of instability are human and environmental impacts including frost heave, shrinking and swelling of soil and rock due to moisture changes, soil expansion and contraction due to soil temperature changes, slope instability, soil consolidation (settlement) and soil erosion (Floyd 1978; Gareau 1983). Vertical changes in benchmarks due to human activities can occur anywhere, and the National Geodetic Survey (NGS) suggests ways of reducing the likelihood of these (Floyd 1978).

Floyd (1978) lists subsurface and near-surface causes of benchmark instability (i.e. crustal motion, subsidence near mines or caves, subsidence due to oil or water pumping) and suggests that their effects usually cannot be economically negated. He recommends that areas where these instabilities occur be avoided.

Soil consolidation and settlement can occur naturally or be man-induced near railroads, highways (Karcz et al. 1975) or large structures (Floyd 1978; Slobodnik and Kool 1983). Regional subsidence due to consolidation of Pleistocene sediments occurs naturally in the New Orleans District of the Corps of Engineers (Eames 1983). To account for this subsidence, deep-set casement-type benchmarks have been placed to depths of 80-135 ft in stable areas to determine benchmark changes in subsiding locations. Eames suggests that perhaps the best way to improve the vertical stability of benchmarks is by using all available geological data in the site selection process.

Benchmark instability is also caused by unstable soils in marshy areas (Reaves 1983). In some southern coastal areas there is a "crust" (3-30 ft thick) overlying an unstable soil zone that is above firm sands. Benchmarks must penetrate the lower firm sand zone. Benchmarks in some southern river bottom areas have also moved 0.1 ft vertically due to water table fluctuations (Reaves 1983).

Changes in benchmark position caused by frost heave can occur where soil freezes and thaws annually (Johnston 1962; Jarman 1955). This problem is most severe where annual frost penetrates deeply. Significant subsurface movement of soil in permafrost areas can occur to depths of up to 30 ft (Black 1957), and conventional benchmarks can be moved several inches a winter due to frost heave and thaw settlement (Linell and Lobacz 1980; Black 1957). A frequently used benchmark designed to be vertically stable in frost areas will be discussed later.

Soil expansion and contraction due to temperature changes cause benchmark movement and are especially active and variable in frozen soils because the soil temperature varies with depth. Benchmarks in bedrock that freezes and thaws can also be moved (Linell and Lobacz 1980). Soil and bedrock moisture changes can cause vertical displacements in benchmarks, especially where expansive montmorillonite clays are common (Johnston 1962). Wetting and drying of clay-rich soils and non-uniform wetting of such soils can make certain sites unsuitable for benchmarks required for high-precision surveys (Slater and Slater 1979; Kryukov and Garevski 1973). Slope instability caused by soil creep, slides or soil erosion can also change benchmark position (Linell and Lobacz 1980).

One of the most effective ways to improve the likelihood of a stable benchmark is to select a good location for installation. Many of the above causes of benchmark instability can be avoided or minimized by wise site selection based on a complete analysis of site conditions.

## PROVEN INSTALLATIONS

Floyd (1978) points out that it is too expensive and infeasible to counteract vertical instability due to deep-seated processes, so the NGS specifications have been developed to resist near-surface movements. Generally, sound bedrock with low moisture content and with joints more than 3 ft apart is acceptable for installation. In unstable soils, permanent benchmarks should be anchored in a stable zone below soil movement and a protective sleeve should extend to the maximum depth of soil movement (Fig. 1).

Where sleeved benchmarks cannot be installed or are not needed, the NGS suggests a sleeveless class B benchmark driven to an appropriate depth based on local soil and weather conditions (Floyd 1978). These benchmarks are not as stable as the class A type. These two types are considered acceptable for meeting the needs of the National Vertical Control Network in that they are designed to resist near-surface movements.

The Mobile District, Corps of Engineers (Reaves 1983), typically uses 3/4-in. diameter Berntsen aluminum rods driven through near-surface soil crusts into stable sands below. Usually the rods are driven 15-45 ft deep in northern Mississippi and Alabama and 80-120 ft deep in coastal areas. Soils are frequently too unstable for conventional monuments.

Many benchmark designs have been used to prevent frost heaving forces from acting on benchmarks (Johnston 1981; Floyd 1978; Crory 1981; Davis 1981; Esch 1983; ACFEL 1957;

Gupta et al. 1973; Johnston 1962; Mackay 1984; Metz 1984), but one of the most frequently used designs is shown in Figure 2. Linell and Lobacz (1980) describe in detail some of the installation procedures and precautions when installing this type of "frost-free" benchmark.

The above benchmark installations are designed as permanent benchmarks. Specific project requirements may not call for the high stability these installations provide. Therefore, project needs should dictate the type of benchmark required. Karcz et al. (1975, 1976) report that all benchmarks move some, but project needs will determine if the likely amount of movement is acceptable. Of the commonly used existing benchmarks, they found those anchored in bedrock, walls and buildings to be the most stable. Those in bridges, culverts and concrete posts, bases and platforms are less stable.

## PRELIMINARY RECOMMENDATIONS

The most important recommendation is to install benchmarks that will serve the needs of a particular project. Elaborate, very stable installations may not be required in every case. Standard installations should be modified to meet site-specific conditions and project needs.

Site selection for benchmarks is very important. Extra time spent in using all available information during site selection could reduce benchmark installation costs and increase the likelihood that the benchmark will be adequate. If the permanent-type benchmarks shown in Figures 1 and 2 are required, construction and installation techniques should be closely followed. These benchmarks have been tested and shown to be stable. Any alteration to the tested design has not been evaluated and may cause an unstable benchmark.

## ACKNOWLEDGMENTS

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Table 1. Sources of Information (other than reports).

| Corps of Engineers* | | Government Agencies | Private Industry |
|---|---|---|---|
| New England | Pittsburgh | U.S. Geological Survey | LHD Associates, Construction Surveyors |
| Baltimore | Memphis | NOAA-National Geodetic Survey | |
| Norfolk | New Orleans | | Geo Tec Services, Inc. |
| Philadelphia | St. Louis | Canadian National Research Council | |
| Charleston | Vicksburg | | |
| Mobile | Kansas City | Geodetic Survey of Canada | |
| Savannah | Omaha | | |
| Wilmington | Ft. Worth | Alaska Department of Transportation | |
| Buffalo | Galveston | | |
| Chicago | Portland | | |
| Detroit | Seattle | | |
| Rock Island | Los Angeles | | |
| St. Paul | Sacramento | | |
| Huntington | San Francisco | | |
| Louisville | | | |

* 38 questionnaires sent out; 24 were filled out and returned; 5 inputs via phone and letter.

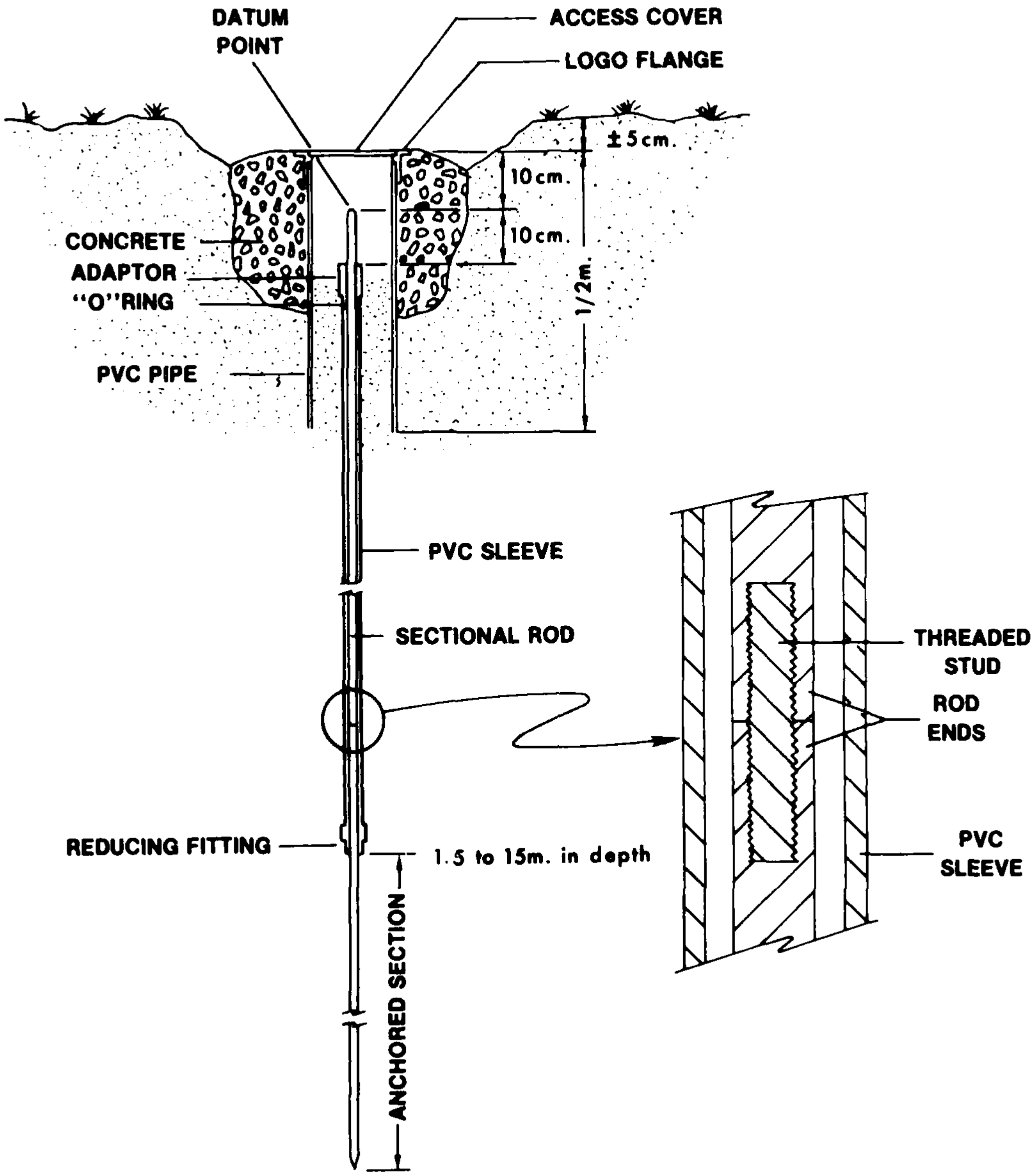


Figure 1. Sleeved class A benchmark to counteract frost heave and shrinking and swelling of expansive soils (from Floyd 1978).

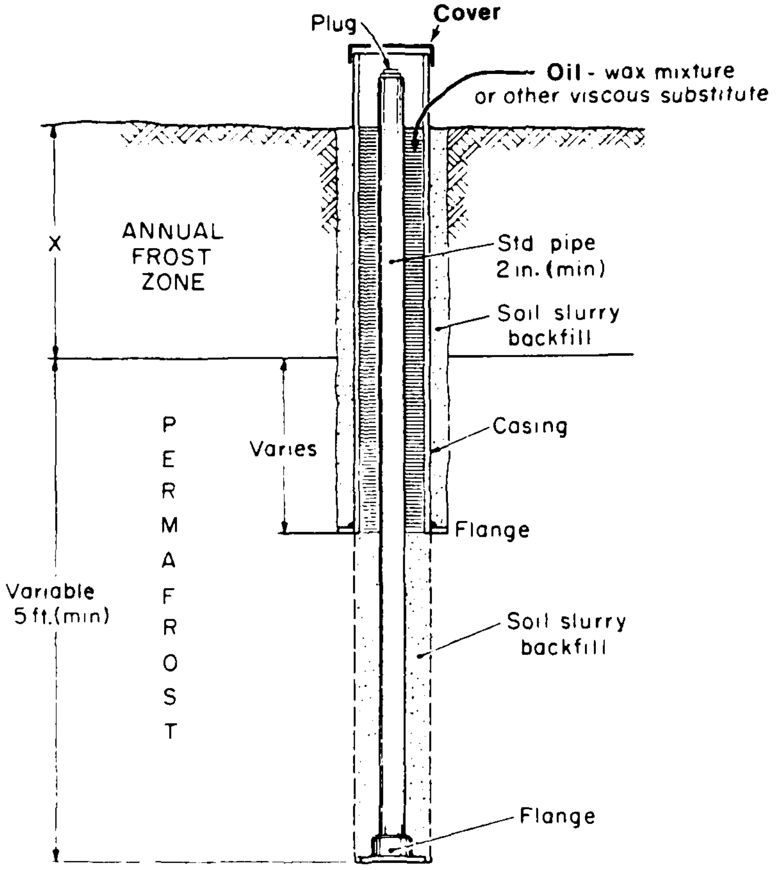


Figure 2. Recommended permanent "frost free" benchmark (from Linell and Lobacz 1980, p. 256).

SESSION VIII: TOPOGRAPHIC EQUIPMENT DEVELOPMENT

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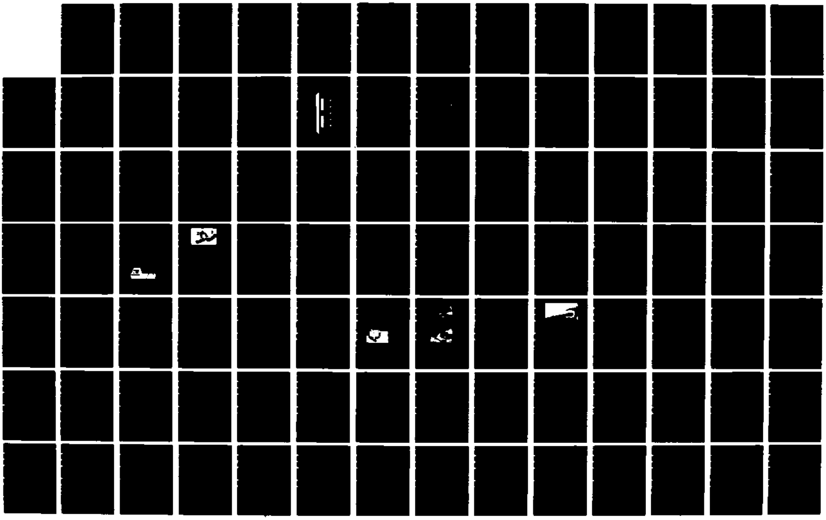

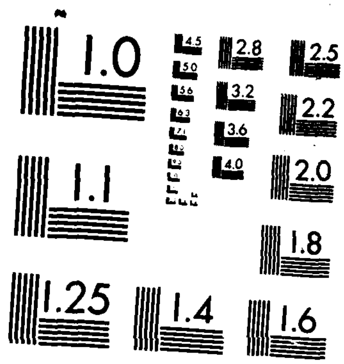


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

## DETERMINING AN AZIMUTH WITH A NORTH SEEKING GYRO

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Kevin is a 1982 graduate of West Virginia University where he majored in Mining Engineering.

### ABSTRACT

Surveyors frequently require an independent means of determining an azimuth. Traditional methods, a magnetic compass reading or stellar observation, suffer from limitations of accuracy or availability. Another possibility is the use of the North Seeking Gyro which overcomes both of these defects. This paper gives a brief description of how the gyro works, effective observing procedures for its use, and results of some field observations made by the Mobile District. The gyro is shown to be an efficient and precise way for obtaining geodetic north even in situations where other techniques cannot be used.

### INTRODUCTION

The instrument known today as the gyroscope was invented some time before 1813 and was called the precession machine. This instrument was used to demonstrate the precession of the earth while it rotated on its axis and revolved in an elliptical orbit around the sun. It wasn't until 1852 that the name gyroscope was proposed for these types of instruments. During the next 50 years, there were several different types of gyrocompasses designed and tested. In 1909, Elmer A. Sperry patented a gyrocompass in the United States of America. At about the same time people began thinking about using the gyrocompass to find direction in a mine. A paper presented to the Institute of Mine Surveyors in 1919 described a gyrocompass that could be used for this purpose. Two instruments were designed and constructed in the years 1924 and 1936 for use in mine surveying. Both of the instruments turned out to be too heavy for mine work.

In 1948, an instrument called the meridian indicator was built from a gyroscope by Dr. Jungwirth. The meridian indicator consisted of the outer globe of the gyroscope being rigidly attached to the base of a Fennel theodolite and mounted on a tripod. This instrument was taken to South

Africa where it was used in the gold mines for the next 10 years. The inner accuracy of the meridian indicator was about one minute of arc and had a precessional swing of 22 minutes. In 1961, the Fennel gyrotheodolite was produced and weighed a little more than 50 kg. A few years after this, two smaller instruments were produced. One of these instruments was produced by Fennel and the other by Wild Heerbrugg in Switzerland. Wild Heerbrugg introduced the gyrotheodolite known to us today as the GAK-1.

## PRINCIPLES OF THE SUSPENDED GYROCOMPASS

The gyro is nothing more than a wheel, rapidly spinning about an axle, and mounted in a gimbal. The toy gyroscope which you may have played with when a child is an example. One of the most noticeable characteristics of the gyro is its resistance to a change in the direction of its spin axis. If a force is applied to the axis of rotation in order to change the direction of that axis with respect to space, the axis will rotate, or precess, at an angle of 90 degrees with respect to the direction of the force.

Now imagine a gyro gimbal which is suspended by a thin tape above the earth's equator. Within the gimbal is a rotor capable of being spun at high speed. Initially the gimbal is aligned so that the spin axis of the rotor is pointing in an east, west direction. Now, the rotor is spun so that the system becomes a gyroscope. Then, as the earth rotates, the rotor axis will in effect, be tilted downward with respect to outer space. The gyroscope resists the motion by rotating about the axis of the suspending tape.

The rest position for this configuration is when the gyroscope is aligned with its axis of spin in a meridian plane. In this orientation the gyro will be translated by the earth's rotation but will not experience an angular change. (That is to say, the spin axis will not be tilted by the earth's rotation.) If the gyro is suspended above one of the earth's poles, the spin axis will always be aligned with one of the meridans, and no tilt of the spin axis can occur. Consequently, the gyro is at a rest position.

At a point between the pole and equator, the gyro will still seek to point north, but the precessing force will be a function of the latitude.

If the gyro is pointed in a nearly north direction, it will swing (precess), towards north. As it passes north, the force will change direction. However, by this time, rotational inertia about the suspension tape axis will force the gyro past the rest point. Thus, the gyro will swing back and forth in simple harmonic motion with both the torsion in the suspension tape and the gyro force causing the swings. At a point near the center of the motion lies true north. Using an optical lever technique similar to that of old fashioned galvanometer, measurements are made of the amplitude of swings on either side of the zero mark of a reticle scale, and the time at which the gyro swings by that gyro mark. A brief set of calculations then yield a correction to the theodolite plate reading to obtain the direction of true north.

## THE WILD GAK-1

The Wild GAK-1 Gyro Attachment is a small gyro which may be mounted to a T2 or T16 theodolite to find the direction of true (astronomic) north. The attachment has been available for over 10 years, but has found limited use, possibly because of a $20,000 price tag and an accuracy which was formerly limited to about 30 arc seconds. The price is still $20,000 but the addition of a vernier modification to the gyro has increased the accuracy to about 5 arc seconds and the usefulness of the instrument at that level of accuracy makes it worth the price.

The U.S. Army Engineer Topographic Laboratories (ETL), purchased a GAK-1 approximately one year ago for the purpose of evaluation. Our desire was to develop techniques for use with the instrument which would produce accuracies on the order of 5 arc seconds. We believed that the instrument would then be useful in at least three applications.

First, the routine measurement of azimuth where either sun or polaris observations are presently made. Because the gyro does not depend on anything external being observed, weather or time of day are not as important. (High winds would probably require an observing tent.)

Second, the gyro might be used for quality control. As more and more Corps survey is done under contract, it becomes increasingly important to develop techniques for checking contractor's work. The GAK-1 may be used anywhere in a traverse to determine an azimuth which can then be compared with results supplied by a contractor.

Third, the use of the Global Positioning System (GPS) is increasing because of its high accuracy and general usefulness. A single measurement with GPS produces the first or second order coordinates of a selected point, but does not produce an azimuth unless a second, intervisible point, is also measured. The gyro may be used to determine the desired azimuth while the GPS measurement of coordinates is being made. This might be done by setting up on the reference point and measuring the azimuth back to the GPS antenna.

## EVALUATION OF THE GAK-1

As is true with any survey instrument, the best results are obtained when sources of error are understood and reduced to a minimum. In the gyro, there are four major sources of error.

The first source is the proportionality constant of the tape suspension. The torque provided by the suspension is a function of the cross section of the tape as well as other factors. A method of calibration is given by Wild, however an unacceptable residual error remained. Techniques of reducing this error were discovered in the course of field tests and were incorporated into procedures for instrument use. Details of these tests are forthcoming in a manual on use of the GAK-1.

The second and third sources of error lie in the measurements of the amplitude of the gyro swings about north, and of the times at which the gyro swings through the zero mark of the measuring reticle. The amplitude errors are reduced through a modification to the instrument by the Royal School of Mines in England. The modification is an optical vernier similar to parallel plate attachment to the automatic level. The timing errors may be reduced through multiple readings of the zero crossing of the crosshair.

The final error lies in the fact that the gyro axis and the T-2 axis disagree because of the mechanical coupling of the gyro to the theodolite. This means that the gyro must be set on a line of known azimuth and the difference in pointing determined. This difference will remain constant unless the theodolite encounters rough handling.

Tests of reproducibility were performed on an outdoor line near ETL. A target was set up and carefully plumbed over a mark at a distance of approximately 200 meters from the instrument. Frequent measurements were made of the azimuth of the mark over a period of about two months. Early measurements indicated improvements to the measuring procedures and these were incorporated into later tests. The reproducibility tests were evaluated, and from the analysis, operating procedures evolved which may be used to obtain accurate and efficient field results.

These operating procedures were further tested in cooperation with the Mobile District. The instrument was taken to an area near Dalton, Georgia, and district personnel were trained in the use of the instrument and in data reduction techniques. The District survey team then made measurements of a large number of azimuths under a variety of operating conditions over the next two months.

Computer programs were also written for data reduction and for the Grid to Geodetic coordinate transformations which are necessary to make the results useful.

## RESULTS

A certain amount of skill needs to be developed in order to get the best results from the instrument. However, one day of practice seems to be sufficient for an experienced instrument man. The first day at Dalton, Georgia was spent teaching District personnel on the operating procedures of the instrument and to do data reduction. The second day the crew began taking measurements and determined the azimuth of two different lines. On the third day, the same two lines were used to determine the repeatability of the gyro and an additional two lines were measured for the first time. A two man crew can determine at least four azimuths per day.

The next two months were spent taking repeated measurements of known lines to test the accuracy and repeatability of the instrument. The coordinates of the points on these lines were either established by GPS or they were published. After

determining several azimuths on known lines and gaining confidence in the instrument and themselves, the survey crew started taking measurements on lines that were not known. Results comparing the known azimuths and the GAK-1 azimuths can be found in the following tables.

| LINE | GAK-1 AZIMUTH | USC & GS PUBLISHED AZIMUTH | DIFFERENCE (SECS) |
|---|---|---|---|
| 1 | 233-53-53 | 233-53-48 | 5 |
| 2** | 57-21-49 | 57-21-35 | 14 |
| 2 | 57-21-39 | 57-21-35 | 4 |
| 3 | 145-42-55 | 145-42-55 | 0 |
| 3 | 145-42-53 | 145-42-55 | 2 |

| LINE | GAK-1 AZIMUTH | AZIMUTH COMPUTED BY GPS COORDINATES | DIFFERENCE (SECS) |
|---|---|---|---|
| 4 | 294-38-04 | 294-38-02 * | 2 |
| 5 | 248-04-16 | 248-04-19 * | 3 |
| 6 | 293-57-55 | 293-57-44 *** | 11 |
| 7 | 281-18-45 | | |
| 7 | 281-18-43 | | 2 |

* The azimuth was computed from coordinates established by GPS receivers.

** Because of the large difference between the observed and published azimuths, a second set of observations were taken approximately one month later. We feel that a blunder was the main cause of the large difference on the first set of observations.

*** The coordinates for one point on this line were published and coordinates for the second point were established using GPS receivers. This could be the reason for the 11 second difference.

## CONCLUSION

The last year has been spent making experimental observations with the GAK-1 to determine the operating procedures that would give the best possible answer. During the course of these tests, the techniques were refined to produce the highest possible accuracy commensurate with practical field usage. The experiments have been confirmed by a survey party from the Mobile district. From the results of these experiments and field tests, we at ETL feel that by carefully following these procedures, the accuracy and repeatability of the GAK-1 is $\pm 5$ arc seconds.

# FIELD TO FINISH SURVEYING
# WITH THE WILD SURVEYING SYSTEM

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## ABSTRACT

The processes by which survey measurements are made, recorded, computed, drafted and located upon the ground, have historically been very time consuming, requiring a massive investment in manpower and equipment to perform the work. A crying need has long existed for a resolution of this problem. The solution must be universal to adapt to the specific needs of a wide range of tasks and individual users. The focus of this paper is to explore the capabilities of the total Field-to-Finish solution available from WILD HEERBRUGG INSTRUMENTS INC on a turnkey basis, utilizing the modular T-2000, Distomat, GRE3, WILD HP Survey Computer System. A fully automated data handling package has been achieved from initial survey measurement to final drafting of the map. The "finish" capabilities of the system includes loading stakeout data from the computer into the data collector to provide direct field control of the actual field equipment. The modularity of the system allows individual components to be matched to the requirements of the task, providing maximum productivity while minimizing the hardware requirement. This new level of technology will have a profound effect upon the productivity of surveyors in the immediate future.

## INTRODUCTION

The traditional tools of the surveyor have been the theodolite, chain, field book, calculator and drafting board. During recent years, the technological impact of electronics has affected each of these tools. The appearance of electronic distance meters (EDM) has dramatically changed the way the surveyor measures distances. Computers and drafting plotters are becoming more common in small engineering offices across the country. In the very near future, nearly every advanced tool we use will contain some kind of computer device. The current trend in surveying equipment is the Electronic Tacheometer with electronic field data recording. These instruments are often referred to as "Total Stations", a term originally coined to mean "electronic theodolite with electronic distance meter and data communications", but now used by some manufacturers to refer to almost any combination of optical transit with built-in EDM. When the "Total Station" term is used in this paper, it refers to the advanced electronic theodolite variety.

The main advantages of electronic data recording in a field surveying instrument are error reductions and efficiency improvement. This is achieved because of the ability to transfer field data directly into a computer system for processing.

A complete surveying system must therefore include that computer system along with the necessary software relating to the type of surveying being performed. Experience has shown that it is necessary to maintain direct control over software development and maintenance in order to gain maximum productivity from the field equipment. Outside suppliers of computer software are motivated to develop general purpose packages, not optimized to extract the best level of performance from any one instrument in particular. Recognizing this, Wild acquired the software development team responsible for the success of the Hewlett Packard surveying system, and now provides single-source systems sales and support, which eliminates "passing the buck" when performance of the system is at issue.

This paper will explore the components which comprise the entire turnkey Field-To-Finish system available from Wild Heerbrugg Instruments. The system has been developed as the result of substantial experience with individual end-users who have introduced this new technology into their business operations with substantial improvements in productivity.

## THE WILD T-2000

The system begins with the Wild T-2000 Informatic Theodolite which performs the same angle measuring tasks associated with all theodolites, albeit electronically.

The basic construction of the T-2000 is similar to other WILD theodolites, with one piece castings and rugged steel standing axis for unmatched stability and durability. The battery is located within the T-2000 and powers both the theodolite and EDM, forming a very compact, one-piece modular unit. The T-2000 is equipped with a weatherproof keyboard by which the operator supplies operating instructions to the instrument's internal computer system. Three Liquid Crystal Displays (LCD) are provided on each keyboard. The leftmost display is alphabetic and is used to guide the operator by means of readable messages. The remaining two displays are numeric, for the displaying of operator-selected measurement results.

The T-2000 has an accuracy of 0.5 arc seconds, standard deviation, for a single observation of a precise target in both faces, excluding sighting errors. The resolution of the displays may be selected by the operator to be from 0.1 arc second to tens of minutes. Angles may be read in grads, mils, decimal degrees or sexagesimal degrees, and distances in either meters or feet. The angle reading system is composed of dynamic absolute encoders which scan the entire circle during each measurement, automatically eliminating any circle graduation errors from the reading. Diametrically opposed sensor locations effectively compensate for any residual eccentricity of circle location. This level of precision and accuracy is suitable for applications involving triangulation, field astronomy, deformation measurements, industrial measurements and optical tooling.

A silicone oil compensator adjusts vertical angles readings for minor errors in instrument levelling. Vertical index error is determined by observation of a precise target for vertical angle in both faces. Once determined, the index error may be automatically stored in the memory of the T-2000 where it will be applied to all future vertical angle values measured. The

memory of the T-2000 is non-volatile, so determination of index errors is required only as deemed necessary by the operator. Horizontal collimation error due to minor mis-alignment of the telescope reticle may be determined in a manner similar to the vertical index error and stored in the T-2000 memory. For most applications, this eliminates the need for precise adjustment of the reticle in order to simplify notekeeping during precise angle measurement.

Certain theodolite applications require the instrument to be levelled up to very small tolerances. The automatic vertical angle compensating system in the T-2000 may be used as a precise electronic levelling system during the setup procedure. Using this procedure, it is possible to set up to within 0.5 arc seconds of level, often in less time than would be needed to level the instrument by use of the alidade spirit levels.

The T-2000 telescope will accept all existing objective and eyepiece accessories used on T-1 and T-16 theodolites. This feature is in keeping with the philosophy of total modularity and reduces or eliminates the need to purchase special accessories for use on the T-2000.

The T-2000 may also be directly connected to an external computer system. When connected in this manner, the computer may take direct command of all T-2000 functions if desired. The computer may cause the contents of the T-2000 displays to show special messages for the operator and eliminate the need for the operator to do much more than point the telescope at a target and press the record button. The T-2000 transmits all measurement and control information to the computer when required. This direct connect capability is used extensively in coordinate measuring systems in industry.

## T-2000 WITH DISTOMAT

The entire line of Distomat series distance meters may be used interchangeably with the T-2000 by attaching them to the standard mounting plate supplied on the telescope. Once attached, the instrument becomes capable of providing the operator with all forms of information available from only the most advanced "Total Stations". Due to the very small and lightweight design of the DI-4 and DI-5 series distance meters, the T-2000/DI-5 combination makes a compact "Total Station" unit having the benefits of portability, cordless operation, modularity and high-accuracy measurements.

The T-2000's user-friendly keyboard allows the operator to easily set the horizontal circle orientation, the coordinates of the starting point of a traverse and the height of instrument. The T-2000 will compute and display complete sets of all pertinent data regarding the location of any point measured during the survey. The operator may select to read the horizontal angle, vertical angle, slope distance, difference in height, elevation and coordinates of the point as desired. If the T-2000 has been given an azimuth and distance for a point to be staked out, the difference in angle and difference in horizontal distance may also be read from the displays.

The T-2000 may be used to traverse through new points by simply instructing it to remember the coordinates and azimuth to the

new traverse point. When the point is occupied, the operator instructs the T-2000 to change to those new coordinates and orient the circle on the new back azimuth.

## THE WILD GRE3 DATA TERMINAL

The GRE3 data terminal is a stand-alone electronic data recorder with user programming capability. The programming option gives the operator the ability to customize the data terminal to match his requirements. The GRE3 is an intelligent, weather-proof, rugged, non-volatile data storage device. The format of the contents of the GRE3 may be selected by the operator, permitting the GRE3 to emulate the operations of data collectors made by other firms. Up to 4000 complete measurement "blocks" may be stored in the GRE3 at a given time, far more capacity than would be needed for any daily task. A measurement "block" consists of all angles and distances necessary to define the position of a point, along with status information of the instrument generating the data. A second type of "block" is often used to control external computer systems by the use of coded information. Sufficient room is available in these "code blocks" to direct a computer for any task. The GRE3 provides a prompt display and two numeric displays similar in operation to the displays of the T-2000. Full field data editing is provided by the GRE3 from it's keyboard.

The GRE3 may be used as a stand-alone unit with conventional transits and EDM's if desired. Used in this manner, the operator presses the "MEAS" key when he desires to record a measurement. The GRE3 then prompts him to enter the values required for the data format in use at the time.

If the GRE3 has been equipped with the BASIC programming option, it may be programmed by the user to perform any required task. The program language is Microsoft BASIC, one of the most common languages in the micro-computer industry. The program memory is separate from data storage so data capacity is not diminished by use of this option. The BASIC program may access the contents of data storage and may be used to drive the operation of a remotely connected device such as the T-2000. Programs and data may be stored on magnetic tape cassette or as bar code if desired, as well as the office computer system.

The GRE3 may be connected to other computers and printer devices by way of an RS-232 communications interface. For long distance communications, telephone modems may be used. Data and programs stored on an office computer system may be sent to the GRE3 using the RS232 interface. In keeping with the totally modular concept, the GRE3 may be connected directly to the T-2000 or may be connected to any of the Distomat series EDM's by way of a voltage control module. If connected to a Distomat, the GRE3 may receive slope distance and instrument status data directly from the Distomat when making measurements. The GRE3 will then ask the operator to supply the angle values for the measurement block.

If connected to the T-2000 with Distomat, the GRE3 forms the perfect electronic link between the field equipment and the office computer. Entire measurement blocks are created on the GRE3 by simply pressing the "ALL" button on the T-2000 keyboard.

## THE WILD/H.P. SURVEYING SYSTEM

Early in 1983, WILD acquired the exclusive rights to market and distribute the surveying software packages that had been developed and marketed by Hewlett Packard in the past. This was the culmination of a decision by Hewlett Packard to depart from the surveying instrument and software market. In order to maintain the excellent support of past software packages and provide for systematic future software development, WILD formed a software support group composed of the Hewlett Packard employees who had performed that duty in the past for Hewlett Packard. This action provided for continuity in the transfer of software support from Hewlett Packard to WILD.

The computer system is based upon the popular HP 86B desktop computer. All accessory items such as monitors, disk drives, printers, plotters, etc., are modular units of various sizes and capabilities that are combined by the user to meet his requirement and budget. This level of flexibility allows one to begin with a minimum size system and expand as required in the future. Entire turnkey systems from field equipment to office computer and software are available from WILD as a single source supplier, a distinct advantage when support or maintenance is required.

The most important parts of any computer system are the programs or "software" that permit it to solve the user's problems in a straightforward manner. WILD survey system software has been developed over a great period of time, beginning when Hewlett Packard first entered the survey software market. As user's became more educated about their computers, and as computers have become more technically advanced, the best suggestions of users and selections of computer equipment have been made to form the current software capability. Data generated on older systems may be transported to newer equipment with the assistance of WILD system support personnel. This cross system support capability is not usually found on other systems.

Applications software for the system is packaged in modular "volumes", addressed to specific diciplines of surveying. Each individual volume may be used without the others if desired. The volumes share a common data structure which permits each volume to operate on data generated from the other volumes.

Volume "C" software is used for all coordinate geometry calculations of a design nature. This is the basic volume of most surveying applications in traversing and project computation. The volume also includes many job-specific applications such as deed description checking and screen plotting. Still other applications are in the computation of building layouts, streets, lots, etc.

Volume "D" software is the latest development for the WILD surveying system and is used to integrate the field operations of a surveyor using the WILD T-2000 Theomat or TC-1 Tachymat with his office computer system. Included in this volume are programs used for transferring data from the GRE3 data terminal and from the GLE-1 cassette tape reader to a storage file on the computer's disk storage system. Editor capability is provided for managing the data and preparing the paper copy of

the original field notes. Once the data is ready for processing, a compiler program is used to automatically analyze the field data and perform all necessary computations for the creation of coordinate data files used by all other volumes of software.

Volume "F" software is used for the generation of drawings on the desktop or large-format Hewlett Packard drafting plotters. This volume is used to prepare finished drawings for projects developed using volume "C" or "D" software. Editors are provided which allow the plot to be generated in any manner desired by the operator.

Volume "H" software is used for the computation and plotting of earthwork cross sections and profiles. Included are powerful road design routines that save many hours of time in determining mass balances of earthwork quantities.

To make the system even more versatile, many word processing and business accounting programs are available for the system, some developed specifically for job costing and accounting in the survey profession.

FIELD TO FINISH

True Field-to-Finish surveying operations can only be realized when the entire information loop between the field equipment and office equipment is reliably and effectively established. This has been accomplished with the WILD T-2000 Theomat, the WILD Distomat EDM's, the WILD GRE3 Data Terminal and the WILD Surveying computer system. The following scenario depicts the extent to which this system may be applied to a survey project.

A survey has been ordered by a client and all of the preliminary research has been completed. The computer operator using volume D software, loads the GRE3 Data Terminal with programs and data that will be used in the field to speed locating points in the initial survey. Included are programs to perform orientations such as sun shots. Other programs as needed are also included.

In the field, the crew begins measurements for the job, consulting the GRE3 programs and data for assistance when needed. As they make their measurements and record them in the GRE3, they also place code blocks in the data to tell the computer what is being done in the field. The crew is free to mix control traverse measurements with control level loops and topographic detail measurements, so only one trip will be made around the project in order to obtain all the necessary data. In order to gain maximum productivity from the field operator, it is necessary to have a coding convention that is simple enough to use by the relative novice, yet be extensive enough to permit all types of survey observations to be made. The coding system used was developed by Wild to satisfy this requirement as a result of long experience with many users in all parts of the country. Their suggestions and experience with the early systems led to the current code definition which is greatly simplified from early attempts, yet is fully versatile. As soon as the initial survey is completed, they hook up the GRE3 to the office computer, either by direct connection or over telephone lines.

At the office, the contents of the GRE3 are transferred to the computer's floppy disk. Backup copies of the disk are made for the field note archives and a printed copy of the field notes made. If a review of the field notes show blunders in the data, it is edited to eliminate the faulty information. The field data compiler is then selected from volume "D's" menu of selections and the volume "C" and volume "F" data files generated automatically from the field data.

Using volume "C" and "F", other drawings and computations for the project are made. If additional field work is required, the new data may be simply appended to the data on file for continued work. Soon it is time to send the crew back for final stateout of the job. The GRE3 is now loaded with coordinate data and field stakeout programs which will perform the field mathematics without error. These programs will be used to control the T-2000 directly, so imputs will be at an absolute minimum.

This comprises the entire effective Field-to-Finish loop. Nearly all operations having to do with field survey measurements are completely automatic This eliminates transcription and computation errors. As may be noted in the preceeding paragraphs, the loop may be performed as many times as necessary in order to complete a project.

## CONCLUSION

The capability of a true Field-to-Finish system have been realized in the WILD T-2000 Theomat with Distomat, GRE3 Data Terminal and WILD Surveying Computer System. This level of integration of computer technology into a totally modular survey system permits the near total integration of electronics with the operations of the surveyor. This will benefit survey operations strongly in the near future as surveyors using the technology increase their profitability and productivity over their competition.

SESSION IX: AIRBORNE LASERS

# AIRBORNE LASER PROFILING AND MAPPING SYSTEMS

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## BIOGRAPHICAL SKETCH

Joseph Jepsky is President of Associated Controls and Communications, Inc., Salem, Massachusetts. The company designs, develops and manufactures laser rangefinders, laser altimeters, airborne laser profilers, marine radar navigation, oceanographic and tanker docking systems. Mr. Jepsky received his B.S. degree from Syracuse University. He has been involved in the design and development of airborne laser profiling and mapping systems since 1970.

## ABSTRACT

Recent advances in Airborne Laser Profiling and Mapping have resulted in widespread industry acceptance of this remote sensing technology. Both pulsed gallium arsenide and Nd:YAG (neodymium-doped, yttrium-aluminum-garnet) laser profilers are being extensively utilized for mapping, surveying, photogrammetric control and Digital Terrain Modeling (DTM). Incorporation of a microprocessor permits extensive on-board laser signal processing in real-time, and simplifies data recording by providing standard RS-232, parallel binary and analog outputs. Timing data is also generated in an appropriate format for integration of the Laser Profiler with any inertial navigation or microwave positioning system. All data outputs (analog and digital) are simultaneously available before and after processing. The ACCI PRAM III system was designed specifically for penetration of heavy jungle foliage or rain forest, providing true ground data and eliminating months of ground surveying. The high data density rate achieves one data point every 1/2" at 125 mph air speed. Advanced measurement techniques permit range accuracies up to 2 cm to be achieved. The GaAs system is eye-safe and has no range ambiguity. The design approach and results obtained by a number of U.S. and Canadian surveying companies and federal agencies are described.

## INTRODUCTION

Industry acceptance of a microprocessor controlled laser profiling system is a natural extension of the current remote sensing technology. The introduction by ACCI of the first nanosecond airborne timer interval counter integrated with a gallium arsenide laser system design several years

ago provided the accuracies required at pulse rates of 4000 pulses per second to economically perform a wide range of profiling missions. (Accuracy is $\pm$15 cm on a single measurement, 1-2 cm accuracy averaged).

Because of these advances, the Laser Profiling System can economically and efficiently be used for the following applications: terrain profiling, photogrammetric control, digital terrain modeling, forest inventory, gravity measurements, coastal zone studies, stream valley cross-section data, route planning for roads, pipelines, power lines, contouring of hydro-reservoirs, mining areas and irrigation projects.

Much of this work can now be performed over forest cover, rain forests or heavy foliage. First and last pulse tracking enhance the ability to obtain ground true data through forest canopy.

The optical and electronic design factored in the wide range of target reflectivity from .01 for ocean surface, 0.1 to 0.2 for soil, 0.5 for vegetation, and 0.5 to 0.8 for ice.

Advantages of the multi-mode system are: (1) provide laser mapping data in hours in contrast to weeks of work needed with conventional methods by a ground survey team, (2) data is recorded in a digital format simplifying immediate computer processing, (3) permits wave profiling and ice profiling at higher altitudes and speeds, (4) maps both ground surfaces and forest canopy or tree heights, (5) all electronics are incorporated in one system package, (6) can be integrated with any horizontal positioning system, (7) compact size and lightness in weight makes it suitable for helicopters as well as larger aircraft.

For the low altitude applications, altitudes up to 1 Km, the systems use a gallium arsenide injection laser operating in the pulsed mode at ambient temperature as the signal source.

All systems, however, low and high altitudes use the identical PRAM 3A Control Console with the same interconnecting cable permitting the recording instrumentation, interfacing and timing to the positioning systems and camera systems to remain unchanged. Provisions are made for 3 separate software programs to be utilized, operator controlled from the console for maximum flexibility.

For the high altitude applications, two transceivers are available. For surveying and photogrammetric application, a 1-30 pps high power YAG system provides ranges in excess of 10 Km. The beam is 0.5 milliradian and the total system weight is 42 pounds.

For photogrammetric applications or for use with gravity systems, a 1 pps continuous operation ACCI YAG transmitter, uncooled, provides accurate altimetry at ranges to 10 Km. First or last pulse provides excellent foliage penetration to true ground simplifying the scaling task. Total system weight is 30 pounds.

## SYSTEM DESCRIPTION

The system includes a laser transceiver and control console, including power supplies, associated electronics, nanosecond time interval counter, computer, control panel and display.

The laser transmitter uses a gallium arsenide injection laser operating in the pulsed mode at ambient temperature as the signal source. A distance measurement is made on the basis of the transit time required for the light pulse to travel from the laser to a target and back to the receiver. This transit time is, in turn, measured by means of sampling a threshold level crossing on the leading edge of both the outgoing and reflected fast rise time light pulses, which provide timing pulses to operate the start and stop channels of a special low-power ACCI, ultra-high speed digital nanosecond time interval counter.

The gallium arsenide injection diode laser was chosen based on the safety criteria, system trade-offs and ease of modulation at the various pulse rates with a pulse width of $10 \times 10^{-9}$ seconds and a rise time of approximately 1-5 nanoseconds. Gallium arsenide (GaAs) injection laser diodes are commercially available, highly reliable, rugged and are inherently long life devices. The GaAs diodes operate in the near infra-red at a wavelength of .9 micron.

The receiver's silicon avalanche photodiode is the most sensitive known photodetector for pulsed near infra-red radiation. When operated with a narrow field of view, low background and wide bandwidth application, it produces a typical 100:1 increase in system signal-to-noise ratio over comparable silicon PIN photodetector receivers.

PRAM III uses the following techniques for the measurement circuitry. A timing interval is initiated by the transmitted laser pulse through the receiver to generate the start signal for timing purposes. The received signal, after appropriate detection and amplification, is fed to the constant fraction discriminator. This output feeds a high-speed, low output impedance driver to supply the stop signal for the time interval counter. The stability of range measurements to various targets is well below a nanosecond when measured with the ACCI time interval counter.

The ACCI nanosecond time interval counter utilizes a digital phase comparison method to derive $\pm 1/2$ nanosecond counting accuracy.

The Intel 86/05 single board computer performs all mathematical calculations, diagnostics, range gating, computer to computer interfaces, range coversions and output functions for an RS-232 interface.

## System Operation

For the profiling systems, the Control Console permits a number of operator selectable operating modes: first or last pulse to provide a true ground and tree canopy data, averaging of sample sizes (ie. 1,8,16,32,64 pulses or a preset number) and pulse repetition rates of 1000, 2000, or 4000 pps. The laser may also be fired remotely via the sync line at any pulse rate from 1 pps to 4 Khz. The Control Console front panel displays range to 1/10 of a meter, the percentage of valid signals received and a valid light to indicate that good data, above a preset level, is being received.

The display is high brightness, airborne LED display designed for direct sunlight viewing or dimmable for night operation.

An Intel 86/05 single board computer performs all mathematical calculations, diagnostics, range gating, computer to computer interfaces, range conversions and output functions for an RS-232 interface.

The computer is programmed to perform the following tasks:

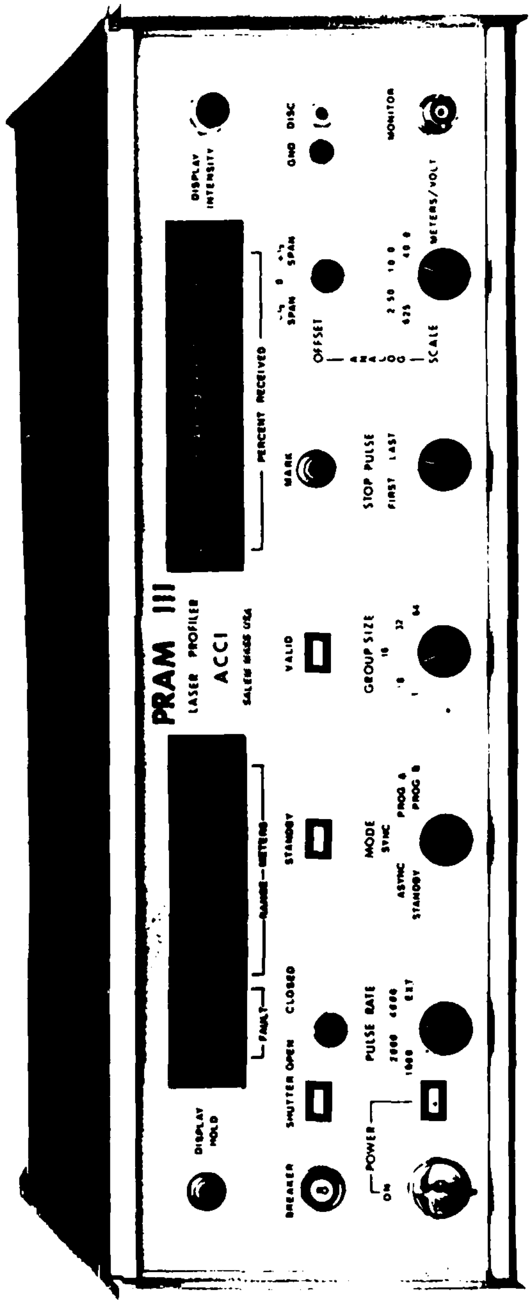
(1) Averaging the selected number of inputs
(2) Conversion of data in nanoseconds to equivalent data in meters
(3) Provides sliding average or block average, operator selectable or on receipt of external sync pulse
(4) Filtering out of data beyond the range of a preset tracking window (range-gate)
(5) Generates RS-232 compatible serial data output
(6) Computer to computer interface for control
(7) Expansion of region of interest of the analog output only, operator controllable, by a factor of 4,16 and prior to recording
(8) Indicates all operating modes
(9) Expansion capability
    (a) Ability to remove aircraft motion in real-time from profile data
    (b) Special software programs

An optional feature is installation of an appropriate accelerometer, mounted in the transceiver to measure the vertical motion of the aircraft to facilitate the removal of the aircraft motion from the laser range measurement.

To date, ACCI has integrated this system with the Honeywell, Ferranti and Litton inertial navigation systems, plus a number of microwave positioning systems. We also have boresighted this with TV and standard cameras for photogrammetric control and X-Y positioning.

PRAM III A

AIRBORNE LASER PROFILER

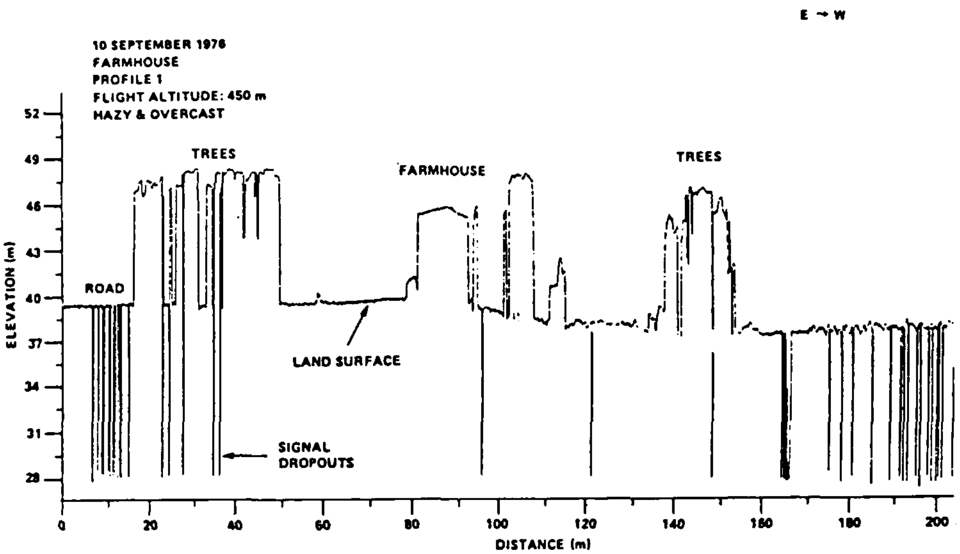



CONTROL CONSOLE

OPERATIONS & FLIGHT PROFILES

We appreciate the permission by the following agencies and surveying companies to describe their laser profiling operations and display representative profiles obtained by various ACCI PRAM systems from 1976 to the present.

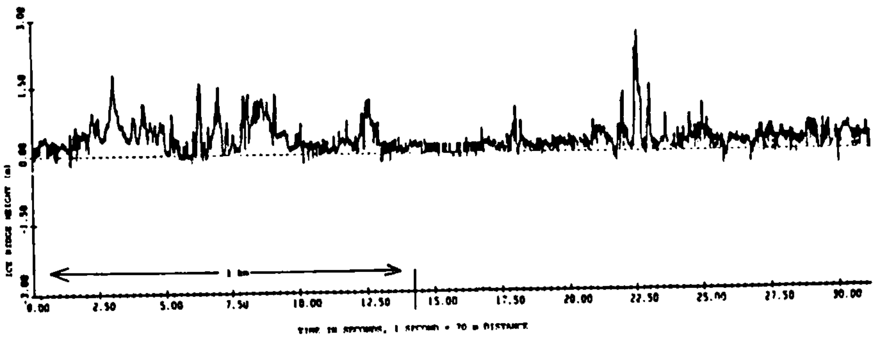
A profile of farmhouses, roads and trees obtained by The Charles Stark Draper Laboratory, as part of their development contract for the U.S. Geological Survey Branch, using an ACCI PRAM system, flying in a Cessna 206 single engine aircraft is shown below. This system is hard mounted.



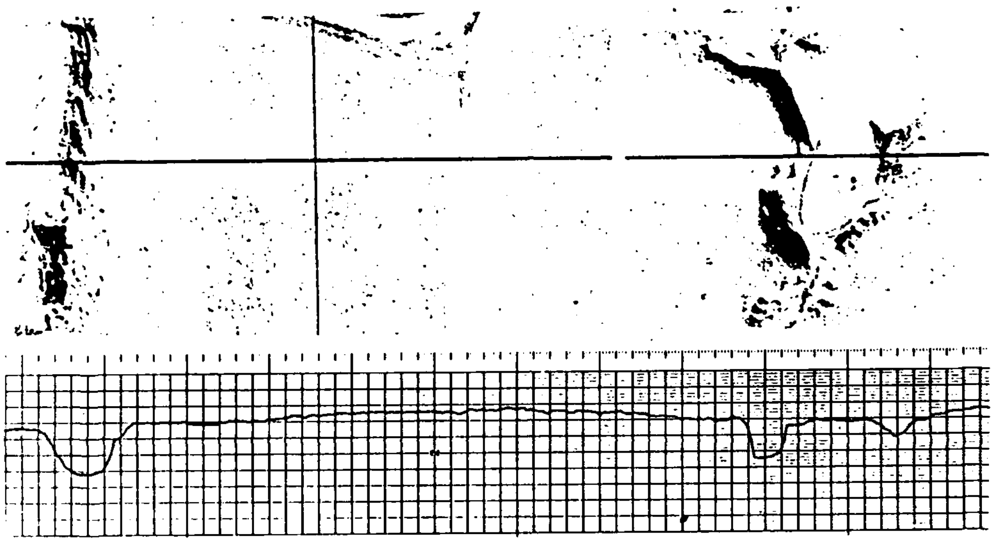
Profile of farmhouse and trees.

LeSchack Associates, Ltd., Long Key, Florida has conducted a major sea ice reconnaisance program in the Arctic Ocean for a number of oil companies and also in cooperation with the U.S. Navy. They have developed a whole suite of computer programs using the digital data from the PRAM III laser for removing aircraft motion, for tabulating statistics of the sea ice distributions and for location of first-year ice, multi-year ice, and open water, as well as for predicting under ice distributions from the surface data. In addition to sea-ice work, they have been using the PRAM III for ocean wave data gathering and analysis, as well as for the usual terrain mapping.

Shown is a profile of sea ice with the aircraft motion removed utilizing the accelerometer data with a special "envelope removing algorithm".




Also shown is a survey of drainage patterns in Southern California. The aerial photography was recorded concurrently with the Laser Profile.



Nortech Surveys (Canada) Inc., Calgary, Alberta utilizes a Ferranti Inertial Land Surveyor (FILS II) integrated with a PRAM III laser altimeter. Laser terrain profiling is performed in a bell 206B helicopter or a small fixed wing aircraft.

A special navigation display is provided for the pilot to allow him to fly long straight parallel lines covering the area of interest. These lines can be as close as 15 meters spacing.

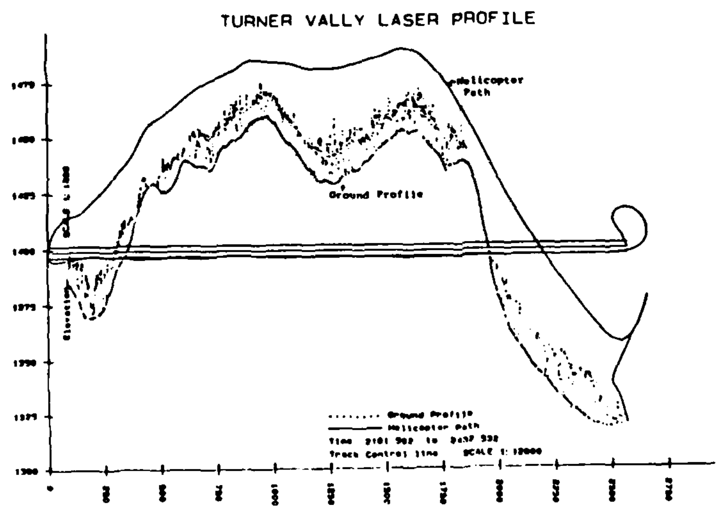
Operations can be planned on the basis of the geographic coordinates of the lines as the inertial system is used to provide real-time positions over the area and no previous ground work need be done other than providing for survey control points about every 5 to 10 km along the lines to permit updating the inertial system and post mission adjustments of the data. In the case of contouring, a widely spaced grid of geodetic control points is laid out and the

area is then covered with multiple profiles from the helicopter. Nortech can provide initial control in remote areas using doppler satellite techniques and then to extend this using their inertial survey system.

Post processing of the data acquired during the profiling runs will likely take place in a field office. Inertial data is adjusted on an HP-1000 computer. Laser data is preprocessed on the HP-1000 computer and then transferred to an HP9845 desktop computer where it is filtered and smoothed and combined with the inertially derived helicopter positions to provide ground positions. These positions are then plotted from the HP9845 on an HP7580A plotter either as contours or profile elevations.

The laser data is edited and stored away as final ground profiles. The files can be processed through Nortech's digital terrain modelling package, providing detail contour maps, prospective "Birds Eye" view of the area and volumetric information between the model and any engineering design surface such as roads and excavations.

Shown is a plot of raw laser data, Turner Valley Laser Profile.



# AIRBORNE LASER TERRAIN PROFILING SYSTEM DEVELOPMENT

WARREN P. LATVALA, R.L.S.
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ANCHORAGE, ALASKA 99501

## BIOGRAPHICAL SKETCH

Warren P. Latvala is presently the Executive Vice President and Chief Operations Officer of International Technology Limited. He is responsible for Itech's operations, foreign and domestic, on and offshore. He studied Civil Engineering at Montana State University from 1961 to 1965, and attended specialized and post graduate survey courses at Portland State University and the University of Alaska. Mr. Latvala received his first registration in Alaska in 1970 and has since registered in Montana, Arizona, Colorado, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, New Mexico and Wyoming. He is a member of ACSM, NSPS, and the Alaska, Montana and Colorado State Land Surveyors Societies.

## ABSTRACT

The development of helicopter portable inertial survey platforms has substantially altered the methods used in collecting survey data. These platforms maintain X, Y, Z positional information as well as platform attitude information. In land vehicle applications, the X, Y & Z values of a fixed offset reference point are directly obtainable. The identical situation exists when a platform carrying helicopter is in contact with the ground. When a host helicopter is airborne, horizontal position of a ground target can be determined via a pendulous hoversight fixed to the helicopter. Determining the elevation of the ground, however, requires measurement of the vertical separation between the helicopter and the ground. The separation measurement problem has been resolved by interfacing a pulsed laser with the inertial platform to determine the X, Y and Z values of the point of laser reflection. By operating the integrated system in a "meander" mode, ground profiles can be obtained. This paper describes Itech's development and operation of the integrated system.

## BACKGROUND

In the course of Itech's inertial survey operations over the past 8 years, we have repeatedly recognized the need for a means of determining ground elevation at points inaccessible for helicopter landings. Itech's primary inertial survey system (ISS), the Litton Autosurveyor Dash II, is capable of determining the horizontal position of such points by hovering the helicopter in which the ISS is

mounted, directly above each point. The helicopter is equipped with a pendulous hoversight through which the pilot can view the ground, or a target such as a survey monument, directly below the hoversight. Each time the pilot maneuvers the helicopter so that the target is centered in the hoversight, he triggers a "pickle" switch, thereby causing the three dimensional position of a predetermined offset from the inertial measurement unit (IMU) to be stored in the memory of the ISS computer. In this instance, the predetermined offset is the position of the hoversight relative to the position of the IMU. As both are fixed to the frame of the helicopter, the hoversight becomes a fixed part of the inertial platform. The three dimensional position stored (latitude, longitude and elevation) provides the horizontal coordinates of the ground target hovered. To determine the elevation of that target however, a means of measuring the vertical separation between the target and the offset position is required.

Various methods of measuring this separation were considered and rejected. The first method of course, was to simply lower a weighted tape, and "pickle" again at the instance the end of the tape touched the target. Only the vertical value of the resulting position would be used, and that value adjusted to target elevation by subtracting the tape measurement. This process would not only be time consuming, by requiring additional hovers, but when used in conjunction with inrtial technology, is roughly akin to transporting the ISS in an ox cart. The use of existing surveying oriented electronic distance measuring equipment was also rejected due to the requirement for a reflector on the target facing zenith. Since the target is inaccessible for a helicopter landing, the reflector would have to be dropped to hopefully land, face up, on the target, and could not be easily recovered. Prisms are too expensive for such use, disposable reflectors offer too small a target considering the motion and vibration in a helicopter and either would be difficult to accurately place and orient.

## LASER TECHNOLOGY

After reviewing the various technologies potentially capable of measuring the separation (radio altimeters and lasers), Itech determined that lasers offered the greatest potential for success. Once this was decided, another basic choice had to be made between high energy, low repetition rate lasers, and lower energy, high repetition rate lasers. Each of these types has its advantages.

The primary advantage of a high energy laser is the stronger beam generated and the resulting increased penetration capability when directing the beam through foliage to determine ground elevation. All of the lasers

considered have the capability to operate on either first return (the reflection of the signal from the first or closest surface encountered in the "footprint" of the beam on each pulse), or last return (the reflection from the farthest surface encountered in the footprint"). First return represents the top of the foliage encountered, and last return represents either the ground, or the farthest surface in the foliage reflecting a signal detectable in the return signal telescope of the laser. Given equal return signal receiver sensitivity, a high energy laser will return a detectable signal from a smaller surface (or through a smaller opening) than a lower energy laser. A price must be paid for this increased penetration capability however. The higher the energy, the less apt the laser is to being eye safe. The higher energy laser also requires a larger power supply, and a cooling system to dissipate the heat generated. Both of these requirements add weight to the system, and weight and power draw are critical features in determining what size helicopter will be required to carry the system. The cooling requirement also necessitates a longer time span between pulses, and results in less dense coverage when the system is transported at a fixed speed. The last drawback to this type system for Itech's use involves the resolution of the distance measured. The distance is determined by the time lapse from when the signal is transmitted until it is returned, counted by a nanosecond timer. The highest resolution quoted by the firms Itech contacted was plus or minus one half meter (+/-0.50m) for this type system.

The laser determined by Itech to be most suitable for our particular application is the lower energy, high repetition rate type system. The particular unit selected is the PRAM III Laser Profiler manufactured by Associated Controls and Communications, Inc. This unit uses a gallium arsenide injection diode laser, and features a selectable pulse rate of 1000, 2000, or 4000 pulses per second, and internal averaging of 1, 8, 16, 32, or 64 pulses by a 16 bit microprocessor. The specified accuracy of the system is plus or minus fifteen centimeters (+/-15 cm) for a single pulse, two centimeters (2 cm) averaged. The laser transmitted is eye safe, and the weight and power requirements of the unit fall well within our parameters for deploying the entire system, ISS, laser, data storage system and operator, in a light turbine helicopter such as a Bell 206 Jet Ranger.

## HARDWARE AND SOFTWARE CONSIDERATIONS

The hardware selection and software development for combining and reducing the ISS position and attitude information with the laser range, was performed by Itech's in house programmers. The on-line portion of the program simultaneously collects positional (latitude, longitude and elevation) and attitude (pitch, roll, and heading)

information from the ISS computer, and laser range data from the laser system microprocessor. The raw data are currently being compiled by an HP 9826 computer, and stored on disc by an HP 9121 dual disc drive. (See Figure 1). This operation is triggered by the ISS computer at preselected distance intervals. Since both the ISS and the laser transceiver are on fixed mounts to the helicopter, once the offset and relative orientation between the IMU and the transceiver are determined, the ISS attitude information provides the three dimensional direction of the laser vector. The laser range provides the magnitude of that vector. The off-line portion of the software developed uses the positional information from the ISS and the described slant range vector to compute the X, Y, and Z coordinates at the point of reflection. (See Figure 2) The off-line software also has listing, data smoothing, editing, plotting, and final coordinate storage and retrieval capability.

All computations to provide navigation, coordinate reference and other required survey parameters are performed by the computer integral to the Litton Dash II ISS. In addition to a great deal of continuing support and information helpful to Itech in interfacing the ISS computer and on-line compiling system, the Guidance and Control Systems Division of Litton Industries developed a new navigation program for Itech's Dash II ISS. This program provides continuous updates of the along-track and cross-track position of the system in relation to a preprogrammed line defined by entering the horizontal coordinates of the end points of that line. The resulting steering information enables the pilot of the transport helicopter to fly precisely along the desired route with no prior physical marking of that route.

## SYSTEM ADVANTAGES

The system developed offers many advantages over technologies and methods now in use. The development of a continuous ground profile is possible without setting foot on the ground. The only helicopter landings required are for updating the ISS at local control, and for the periodic zero velocity updates necessary enroute to maintain ISS accuracy. For mapping purposes, the need for controlled photo identifiable ground points is eliminated, as is the need for thousands of feet of clear sky. In areas where photogrammetric mapping is impossible due to dense foliage, the speed of the host helicopter can be slowed to decrease the distance between pulse "footprints", and proportionately increase the number of pulses that reach the ground over a given distance.

## APPLICATIONS

Specific applications include profiles of centerline for road, railroad, pipeline or power transmission line routes. For reconnaissance, the design engineer can accompany the system and direct the pilot along the route selected from his vantage point in the helicopter. Preliminary plan and profile data can be printed out and reviewed immediately upon returning to the field camp. Upon selection of the alignment, the coordinates of the P.I.'s defining that alignment can be entered into the memory of the ISS computer, and used to navigate the system precisely along that route to collect centerline profile data. Parallel offset lines can be profiled in the same manner if cross sections are a required part of the route survey.

For site mapping, the system can be flown along a predetermined grid or set of parallel lines. The resulting digital data can be transferred on disc or tape directly to a computer automated drafting system, or in hard copy X,Y,Z listing for manual plat preparation.

## CONCLUSIONS

Although Itech plans improvements of this system that will increase its capabilities and potential applications the present configuration meets all of our original goals. In field tests and use on actual projects, the Airborne Laser Terrain Profiling System has proven itself a valuable addition to our inventory of surveying systems.

# AIRBORNE LASER TERRAIN PROFILING SYSTEM
## SYSTEM CONFIGURATION

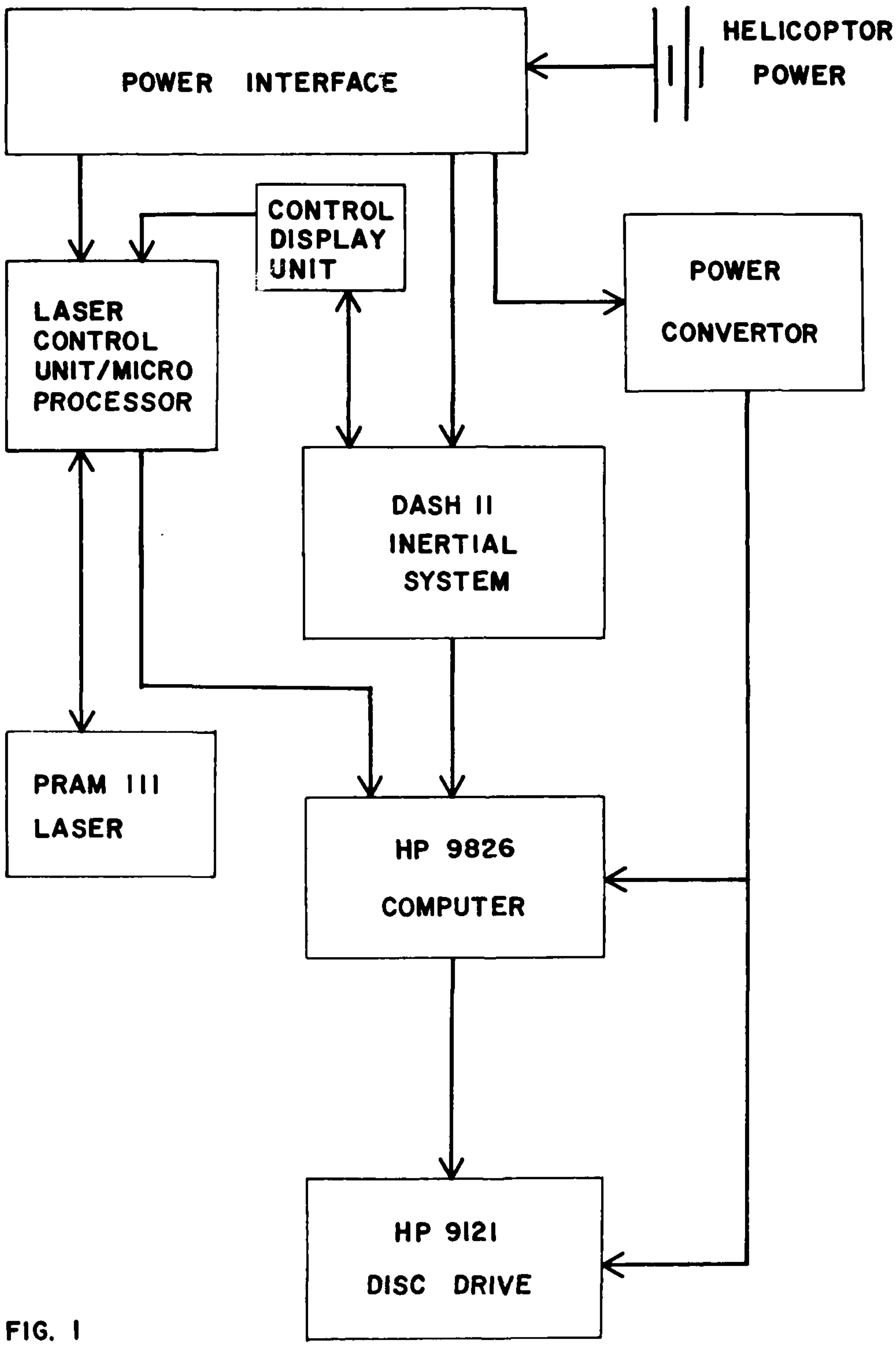


FIG. 1

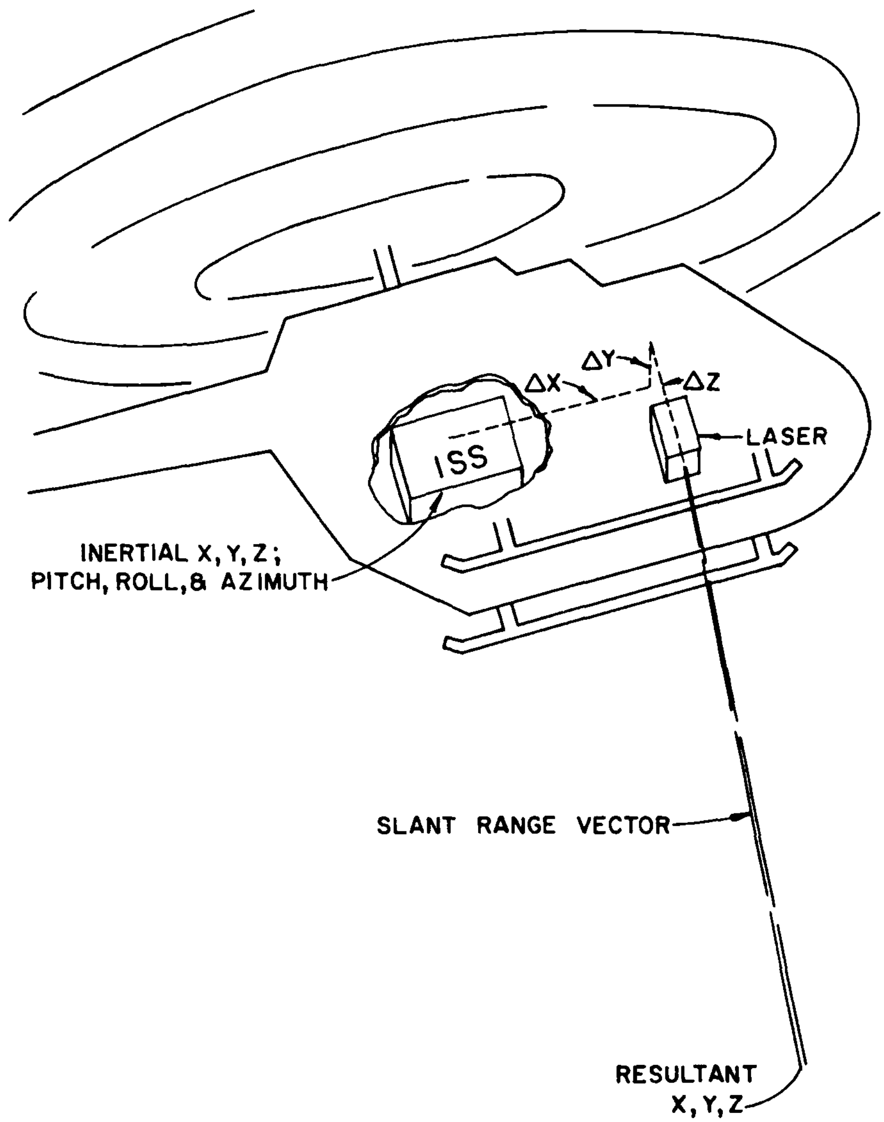
ΔY
ΔX
ΔZ
LASER
ISS
INERTIAL X, Y, Z;
PITCH, ROLL, & AZIMUTH
SLANT RANGE VECTOR
RESULTANT
X, Y, Z

FIG. 2

SESSION X: GLOBAL POSITIONING SYSTEM

# THE POTENTIAL OF THE NAVSTAR GLOBAL POSITIONING SYSTEM FOR THE CORPS OF ENGINEERS, CIVIL WORKS

Kenneth D. Robertson
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BIOGRAPHICAL SKETCH

Kenneth Robertson is a Research Physicist with the Surveying Division of the Engineer Topographic Laboratories. In that position he has developed a number of surveying techniques and instruments for use by Corps surveyors. Included in these are a method for precise monitoring of dams and an instrument for measuring the tilt of dams and lock walls. His current work is with applications of the Global positioning system and the north seeking gyro. He is a graduate of Indiana University.

## INTRODUCTION

The Department of Defense is in the process of deploying a new satellite system for the purpose of navigation and point positioning. While designed primarily for military applications, the system poses great potential for civilian use as well. In particular, the use of GPS in a geodetic mode may yield rapid, accurate survey positions in three dimensions. Thus, in the near future, GPS will become a valuable new tool to the Corps surveyor.

## HISTORY

Man has always used the stars to navigate or find directions and more recently to fix his position on the surface of the earth. When the first artificial satellites were put into orbit they were used almost immediately for geodetic positioning. From its beginnings in the late 50's with the use of satellite tracking cameras, the technique has evolved into the the modern systems of today with microwave transmitters on board the satellites.

The Army SECOR (Sequential Collation Of Range) and the Navy TRANSIT are examples of such electronic systems. The SECOR system was intended for precise geodetic positioning through range measurements and was only partially successful. The TRANSIT navigation satellites are still in use today for both navigation and point positioning.

## THE TRANSIT DOPPLER SYSTEM

Because the TRANSIT navigation system is one which has been remarkably successful and has been adapted to the civilian sector, and because NAVSTAR may replace this system, it would be of interest to understand TRANSIT's evolution and history.

TRANSIT was developed for military use starting in 1958. It was designed to be a marine navigation aid and that remains its primary role today. However, in the late 60's equipment was developed to use TRANSIT for surveying. The most important application is for point positioning. In contrast tosatellite position fixes taken on a moving vessel in which each position fix is used independently to update the dead-reckoned position, fixed point positioning requires data from multiple satellite passes at a single location. With appropriate data processing techniques, good survey results may be obtained, thus avoiding the land traverse required by conventional survey methods. A horizontal positioning repeatability of less than 5 meters can be expected after 25 satellite passes.

A second way of using the TRANSIT satellite is in a relative or translocation mode. In this mode, data from two or more receivers are combined in such a way that the relative position between the receivers may be found to less than one meter. When one receiver is placed on a known point, the coordinates of the other point may then be accurately determined.

The federal Geodetic Control Committee has tested the TRANSIT system in the translocation mode. They say:

> "Analysis of the test results indicated that with about sixteen passes (generally one day of observations) it is possible to compute the position of an unknown point relative to a known point to an accuracy of plus or minus 40 cm for latitude and longitude and about plus or minus 1 meter for the elevation (1 sigma estimates)."

## USES OF THE TRANSIT DOPPLER SYSTEM

The TRANSIT system was originally designed for navigation of ships and it is to fulfill this function that the system is mainly used. But surveying is also an important use, and the one which we are concerned with here. Following is a list of some of the present uses of TRANSIT for surveying. These are, of course, uses to which the Global Positioning System would also be put.

Seismic Line Control. TRANSIT may be used to provide control for the end points of a seismic line and for quality control of the interior part of the line where conventional control surveying techniques are currently used.

Gravity Surveys. TRANSIT provides endpoint control for gravity surveys performed with an inertial surveying system.

Control for Offshore Positioning. TRANSIT may be used to determine the exact position of offshore drilling platforms and ships.

Mapping Control. Resource mapping using aerial photography requires adequate ground control. This may be provided by TRANSIT in areas where conventional control is difficult to obtain.

Utility Line Control. Particularly in remote areas, a utility line route is selected from aerial photographs. The laying out of this route on the ground is greatly facilitated by utilizing doppler satellite methods.

As you might note, most of the above uses are for surveys which do not require high accuracy. Forty centimeters is not good enough for most types of surveying presently performed by Corps surveyors. Further, the time required for the measurement of a single point is a full day of observations. The Global Positioning System increases the accuracy of these measurements while at the same time reducing the time required for an observation.

## THE NAVSTAR GLOBAL POSITIONING SYSTEM

The NAVSTAR Global Positioning System (GPS) was originally conceived as a tool for military sea, land, and air navigation. The system consists of the three parts: the satellites, the ground control network, and the user equipment.

Present plans call for the system to be implemented using 18 NAVSTAR satellites, with three in each of six orbital planes. The orbits are approximately 20,000 kilometers above the earth, giving an orbit period of 12 hours. With this configuration, a user should be able to receive signals from at least four NAVSTAR satellites simultaneously at almost any point on earth (except the extreme polar regions), at any time.

Information from the satellites is transmitted by means of a pseudorandom code which is controlled by a cesium clock within the satellite. The user equipment measures the time of arrival of the pseudorandom pulses by adjusting its internal code generator to phase match the code being received from the satellite. Then, by knowing the time of arrival of signals from four satellites, it is possible to solve for position in three dimensions plus an accurate value for time. A lesser quality clock is required for use in the receivers.

GPS may be used in several modes, although all may not be available in the future to the civil surveyor. Direct access to the pseudorandom code in a high accuracy **navigation** mode (approximately 10 meters) may be denied to all but a few civil users, although a lower accuracy mode (200 meters) should be available.

The technique of most interest to Civil Works users is the **differential**, mode. In this mode, two or more GPS receivers simultaneously receive signals from the same set of satellites. The resulting observations are subsequently processed to obtain the interstation difference in position. If one of the receivers is placed at a known position, the

three dimensional position of the second receiver may be determined. The number of stations determined simultaneously is limited only by the number of receivers available.

Accuracy projections for interstation position determinations using the GPS differential technique range between a few millimeters for baselines of a few kilometers, to a few decimeters for baselines of up to perhaps 5000 kilometers. These accuracies assume observations of from thirty minutes to two hours in length.

## POTENTIAL USES OF GPS FOR CIVIL WORKS

Quality Control. As the Corps of Engineers continues to contract for a greater and greater proportion of their surveying and mapping product needs, while at the same time the number of in-house survey personnel decreases, quality control will become of greatly increasing concern. A GPS antenna may be placed over a mark in the middle of a traverse and used to check a contractor's conventional survey for accuracy. If two intervisible points are checked, an azimuth may also be determined.

Elevations Along the Mississippi River. There is evidence that the whole of the Mississippi river basin is sinking, so that elevation benchmarks along the river are suspect. Since measurements of levee profiles are dependent on these benchmarks they too may be in doubt. GPS could provide an elevation reference which is not subject to these errors. GPS could also be used to measure subsidence of marks along the river with reference to marks 100 kilometers away. In combination with an inertial survey system, measurements of levees would be better able to find low spots. It should be understood that GPS measures elevations to a different reference plane than a conventional leveling survey, and thus is not completely suitable for establishing absolute elevations. However it should measure changes in elevation with full precision.

Elevation Reference for Tidal Gauges. In the same way that GPS could be used to control elevation benchmarks along the Mississippi river, it could be used to check tidal gauge elevations along coastlines. In addition, techniques are being developed that may be useful for determining absolute elevations in certain cases. These might be used to determine the elevations of offshore islands, or wherever it is difficult to determine elevations by conventional methods.

Control in Remote Areas. GPS could be conveniently used to bring first or second order control into remote areas without the usual ground traverse or triangulation net. Present costs for such surveys are in the neighborhood of $750 to $1200 per point.

Continuous Monitoring of Dams. There is also an interesting potential for continuous monitoring of dams and other large structures using GPS. In this case several antennas would be permanently mounted on the structure with another, reference antenna, mounted on stable ground a few kilometers away. Relative, two dimensional movements could be detected at a level of less than five millimeters.

## COST

The approximate cost of a basic NAVSTAR GPS receiving and processor unit will initially be about $300,000, but will probably drop to the $125,000 range by 1987. Cost of a single receiver alone should be about $50,000, and this will be the most probable purchase for the private surveyor. He would operate the single receiver at various sites as a remote station while a service company in his area would man the reference station continuously. The service company would also processe his collected data and provide him with the results. This might be the desired entry level for a Corps District as well.

## THE FUTURE

It is becoming increasingly accepted that any future land records and information system will be based on a nationwide geodetic framework. This would not only provide an accurate and efficient means for referencing data, but also a uniform and effective means for distributing land records. In this regard, GPS represents a potential major breakthrough in providing efficient control densification. At the same time it poses the question as to whether densification is necessary.

The probable future configuration for use of the NAVSTAR GPS system by the private surveyor will be to have a single base station (which may be operated by a service company) at a convenient point within a limited geographic area, and any number of mobile stations operated by private surveyors (who may either own or lease the units). Survey reference would always be to the geodetic control network without the necessity of bringing control to the site in the conventional sense.

## IN CONCLUSION

The NAVSTAR Global Positioning System has been shown to be an accurate method for measuring positions on the face of the earth in as little as one-half hour. As the system becomes more widely available, it will find widespread use in the civilian and Corps civil works areas. Several of the Corps Districts have already used the system under a lease arrangement with excellent results. The Corps will find NAVSTAR GPS an increasingly valuable tool in its future.

# MACROMETER™ Interferometric Surveying System - Status of an Operational GPS Tool

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## BIOGRAPHICAL SKETCH

Jimmy D. Cain is Manager of GPS Services at Aero Service where he is responsible for GPS survey operations and equipment sales. He received his degrees in Meteorology and Physical Oceanography from Texas A&M University. He served as Executive Vice President and General Manager of Racal Survey, Inc. prior to joining Aero Service to head up their GPS operations. Mr. Cain is a member of ASCM, AAUP, Chi Epsilon Pi, Phi Kappa Phi, Pi Mu Epsilon, Sigma Gamma Epsilon and serves on the Telecommunications Policy Committee of the National Ocean Industries Association.

## ABSTRACT

The new Global Positioning System (GPS) offers new capabilities in surveying accuracies and applications. The MACROMETER™ system was the first system to exploit the geodetic applications of GPS for commercial applications.

The MACROMETER interferometric survey system was introduced to the surveying community in February, 1982 at the Third International Geodetic Symposium of Satellite Doppler Positioning. During the remainder of that year, refinements in hardware and software led to the development of the MACROMETER 1000 Series, which underwent extensive testing by the Federal Geodetic Control Committee (FGCC) in January, 1983. The U.S. National Geodetic Survey (NGS) acquired a MACROMETER system soon after the FGCC tests and has been using its three units in production for over one year to establish primary geodetic control relative to the U.S. National Control Network. Since that time, MACROMETER interferometric surveying systems have been in daily productive use by federal and state agencies and private industry.

A large number of control projects have been performed in various areas of the world using this equipment. Accuracies achieved for V-1000 single frequency equipment have generally been in the 2-4 parts per million (ppm) proportional accuracy range for 3 to 6 hour observation periods. Accuracies required for many mapping projects (Third Order, Class I and Second Order, Class II) can usually be achieved with observation times of less than one to two hours.

™ - MACROMETER is a trademark of Aero Service Division, Western Geophysical Company of America for Aero Service's Interferometric Survey System.

The MACROMETER 1000-series system has proven to be cost effective for less precise work as well as for highly accurate control establishment. Mapping and construction control densification projects requiring only Third Ordersurveys (1:10,000) can be performed efficiently using the V-1000 equipment in any applications where line-of-sight conditions are hard to achieve for conventional surveying techniques. Inter-station visibility is not required with the MACROMETER system and observations can be taken in any type of weather conditions. For low accuracy mapping projects, several observation setups per day can be achieved and this will improve as additional GPS satellites are launched.

A summary of results from various surveys with MACROMETER systems is provided herein together with operational considerations of the present and proposed satellite constellations.

## INTRODUCTION

The Global Positioning System (GPS) satellite constellation is currently being established by the Department of Defense primarily for military purposes. The system however also offers large breakthroughs in geodetic surveying capabilities which are achievable without compromising the military security aspects of the basic system.

Several methods exist to obtain positions using GPS. The four most significant are:

- SPS or Standard Positioning Service
- PPS or Precise Positioning Service
- Differential SPS
- Interferometric Codeless Techniques

The Standard Positioning Service (SPS) offers general navigation to accuracies of 100 meters and is of no interest in a stand alone mode to the surveying community. The Precise Positioning Service (PPS) requires access to the military P-Code and will require strict cryptographic procedures for its use. Furthermore, its inherent accuracy is still only at the 10 to 15 meter level and thus it is not applicable to most geodetic and survey applications. Differential SPS offers significant accuracy enhancements but still is not expected to yield real-time accuracies better than several meters (at best). The only method of the four listed which will provide accuracies at a high enough level to satisfy a surveyors requirements is the employment of interferometric techniques. The MACROMETER interferometric survey system is the pioneer in this field and repeatable relative accuracies of from two to four parts per million (ppm) are standardly achieved in routine survey operations when high accuracies are required.

The MACROMETER V-1000 series was introduced in 1982 (Counselman and Steinbrecher, 1982) and has been used extensively in tests and survey operations over the past two years. These include many routine production jobs requiring accuracies of Third and Second Order as well as highly

precise First Order work. In this paper a number of results obtained in various projects will be examined and some future developments previewed. An overview of operational considerations is also given.

## EQUIPMENT DESCRIPTION

The MACROMETER single frequency system typically consists of two or more V-1000 Field Units and a P-1000 Data Processor. The V-1000 Field Unit has two components: an antenna and a field receiver/terminal that are connected by a coaxial cable of up to 30 meters (100 feet) length during observations. See Figure 1 for a typical field setup.

The receiver/terminal includes the following items: An electronics assembly, a remote control/display unit (CDU), and a dual DEC Tape II cartridge drive.

The electronic assembly is comprised of:

> An analog drawer containing the analog circuit modules;
>
> A power drawer containing the regulated power supplies and quartz oscillator;
>
> A digital drawer containing the digital electronic modules including DEC LSI-11 microcomputer, clock subsystem, and memory modules.

The data are normally processed on the Model P-1000 Data Processor. This is a desk top system built around the DEC LSI-11 microcomputer (Figure 2). The P-1000 is comprised of the following items with all necessary software: video terminal, dual DEC Tape II cartridge drive, 10 Mbyte Winchester disk, 8-inch floppy disk, printer and modem.

## MACROMETER V-1000 OBSERVATIONS

The MACROMETER interferometric system does not require interstation visibility to achieve its results. For relative positioning, one V-1000 is placed at a location with known coordinates and one or more (usually two or three) V-1000 field units are placed at desired points where positions are to be established. The receivers then record phase data simultaneously at a number of time epochs (normally sixty) over a predetermined observation period. An observational period normally runs from one to four hours depending on accuracies desired and location. Longer observations are sometimes required elsewhere in the world due to poor satellite constellation geometry.

The number of receiver setups achievable per day is a function of the geographical location of the survey area, the required survey accuracy, project logistical considerations, and the condition of the GPS satellite constellation at that location and date. The number of satellites intervisible, their geometric relationships, and the durations of their visibility windows all affect results. A simulation using the P-1000 is normally run

prior to any field work to determine the optimum setup schedule desirable to obtain required results. Once a schedule is established for a given location and date, it varies little. The rise times and set times of the satellites (the observational window) are earlier each day by approximately four minutes, 3 seconds (about two hours per month). Other aspects of the constellation are normally essentially unchanged over normal field projects of a few days or weeks. The MACROMETER system does not decipher the C/A or P-Codes transmitted by the satellites, but rather treats the signals as white noise and measures the phase of the carrier wave. Standard production equipment currently available is single frequency, using only the L-1 signal or 19cm wavelength transmission. Phase measurements are usually double differenced; that is, differenced between satellites and between receivers. This removes most fixed errors by cancelling instabilities in the satellite oscillators and the oscillators of the receivers. Ionospheric effects also tend to cancel out when the two receivers are not separated by large distances (Bock _et al_, 1984a).

Currently the incomplete satellite constellation only allows for observation during a contiguous period of roughly six hours per day. When the 18 satellite constellation is complete in 1988, then at least four satellites should be simultaneously visible from anywhere on the earth at all times. This will make geodetic surveys with MACROMETER systems much more cost effective than presently. Even with the current satellite configuration, MACROMETER systems can be economically justified over conventional techniques in areas where interstation visibility is difficult to achieve or very high accuracies are required. The removal of line of sight restrictions makes surveys with MACROMETER systems attractive for many tasks--particularly control densification which can be appropriate to many applications. The MACROMETER system can be used to set up a local reference line or network from which further conventional or inertial surveys can be performed.

Aero Service maintains its own Satellite Tracking Network across the United States. From data collected at these stations, satellite ephemerides are computed and are provided to users on a service contract basis from Aero. These ephemeral data are usually provided on a routine basis from three to seven days after a day's tracking is complete. This turnaround time will be decreasing shortly to 2-3 days with software and tracking enhancements which are being implemented.

## SURVEY RESULTS

_FGCC Test and Demonstration._ In January, 1983, the U.S. Federal Geodetic Control Committee (FGCC) conducted a test and demonstration of the MACROMETER Interferometric Surveying System (Hothem and Fronczek, 1983). The FGCC used terrestrial surveys as standards of comparison to assess the accuracies of determinations of baseline lengths, azimuths, and ellipsoidal height differences measured with a MACROMETER Series 1000 system.

Differences between the two data sets were consistent and significantly smaller than expected. As stated in the abstract of the full report: "For lines with lengths ranging from 8 to 42 kilometers, the mean differences for the baseline lengths, after adjustment for a scale difference of 1:455,000 were 0.2 cm with a standard deviation of 1.7 cm. The standard deviations about the mean differences in azimuth and ellipsoid heights were about 0.1 arc second and 4 cm respectively. For a special test network with lines ranging in length of 0.2 to 0.8 km, the mean differences for the baseline lengths were about 3 mm with an rms of 3 mm. The orientation and ellipsoid height differences were consistent at about the 1 arc second and 8 mm level respectively. In summary, the test results indicated the MACROMETER Model V-1000 is a viable survey system that can be used successfully to establish geodetic control relative to the National Geodetic Reference System".

Since completion of these tests, NGS has purchased a MACROMETER system and uses it extensively in establishment of primary national control in applications where survey tower construction was previously required.

Canadian MACROMETER V-1000 Tests. In the summer of 1983, tests were carried out by the Department of Energy, Mines and Resources, Earth Physics Branch of the Canadian Government jointly with the University of New Brunswick (Valliant, 1983). In these tests, 26 base lines were measured in the vicinity of Ottawa over distances ranging from 30 meters to 65 kilometers. On the shorter base lines (30 m and 2200 m), measurements with the MACROMETER system agreed with conventional measurements within 4mm and 9 mm respectively. On longer baselines (13 to 65 km), single observation standard deviations ranged from 0.3 to 2.0 ppm of baseline length in all three coordinates. As stated in the report, "Latitudes and longitudes on the longer baselines also agree with currently available geodetic values to within a few ppm of the baseline length". Agreements were generally within the error limits computed for established data.

EIFEL Network Project. A geodetic network of twenty (20) stations in the Eifel region of the state of Nordrhein - Westfalen, Federal Republic of Germany, was surveyed in September, 1983 using MACROMETER V-1000 systems (Bock, et al 1984c). See Figure 3 for the geographical layout of the EIFEL Network. The data were used to point position one station in the network and also obtain the relative position baseline vectors between all the points. Forty three statistically independent baselines were measured with a total of fifty three baseline determinations. Individual observations ranged in duration up to 3 hours and 25 minutes. The baseline observations were input to a three dimensional network adjustment program to obtain one consistent set of coordinates for the twenty stations. The result was a network "internally consistent at the level of one ppm for baseline lengths and 1-2 ppm for baseline vector components". No external geodetic information was used to obtain these results. The typical baseline length was approximately ten (10) kilometers. The weighted rms of the

vector misclosures prior to adjustment was 14 mm.

This project was extended by an additional campaign in May, 1984 with observations of 22 stations--seven of these in common with the previous data set. Observation duration was up to five hours and baseline lengths consistent with the earlier project. An examination of the total resultant network was reported by Bock, et al (1984b and 1984c) with the following results.

The rms uncertainties for the sixty-seven measured baselines were:

Spatial distance 0.9 ppm (0.9 cm)
Geodetic azimuth 0.9 ppm (0.2 Arc second) and
Ellipsoidal height 1.6 ppm (1.6 cm)

The unweighted rms of misclosures was 1.7 cm and the weighted rms of misclosures was 0.6 cm.

Again, these results prove that surveys using MACROMETER V-1000 systems can consistently yield relative position results at better than 2 ppm closure.

Fall 1984 ASCM Tests. A test network was established in San Antonio, Texas for the fall 1984 ASCM Convention around the convention center over which various survey methods were tested (conventional, doppler satellite, inertial, photogrammetric, and MACROMETER V-1000 systems). Various teams tested the specific equipment types on the test network and reported on the obtained results at the meeting. The surveys with MACROMETER systems for the project were run by the Texas State Department of Highways and Public Transportation using Series 1000 equipment which they own (Merrell, 1984). In order to make two measurement sets per day, two hour observation periods were selected rather than 3 to 4 hours reducing somewhat the potential accuracies to be obtained. The reference station was located about eight miles from the project area where two points approximately 1,200 feet apart were observed. No direct measurements of the short baseline were taken in the test. When compared to values obtained conventionally, the V-1000 systems yielded better than first order horizontal results (1:100,000) even with the shorter periods of observations. Relative vertical accuracy between the two established points were within 0.12 feet (3.66 cm) of those obtained conventionally.

Note that production was doubled by shortening the observation to two hours each, thus allowing two instrument setups per day. This is even with current short (6 hour) satellite observation window. For less precise work, even shorter observations per station are required, thus allowing further increased production.

Routine Production. Aero Service maintains crews performing contract surveys for many applications. While it is not possible herein to detail work on these projects due to client confidentiality, certain observations can be made. Production work with V-1000 equipment has been routinely performed in mountainous terrain in various areas of the

United States with good production under all environmental conditions which allowed access to the required points. The equipment has also worked without failure in humid tropical rain forest environs of South America with no added weather protection other than a simple rain-proof cover for the receiver itself. Surveys have also been performed on offshore oil production platforms tying offshore precise radionavigation transmitter sites to NGS shore control. The equipment has been installed in jeeps and 4-wheel drive trucks, helicopters, small fixed wing aircraft and other carriers.

Applications of production surveys have included power line and pipeline right-of-way control densification, highway construction integrity and control densification, photogrammetric mapping control, transmitter sites, and others. Subsidence monitoring, dam deformation, and other time variable surveys can be performed with a high degree of accuracy (a few ppm) if required.

MACROMETER V-1000 equipment using GPS signals routinely surveys mapping and right-of-way projects to accuracies of better than 1:20,000 and 1:10,000 and in many applications is cost competitive to conventional techniques. When higher accuracies are required, the cost effectiveness of the equipment is even further increased.

Point Positioning Results. Bock, et al (1984a) summarized several tests on the point positioning capabilities of the MACROMETER single frequency system. Several points were examined and the conclusions reached that MACROMETER V-1000 system can yield point positions with accuracies to the several meter level using only several hours of observation. This is true today with the existing incomplete satellite constellation and results will certainly improve as the constellation is enhanced to its full coverage of 18 satellites.

Point positioning accuracies obtainable with MACROMETER V-1000 systems at this time are at least equal to those which can be achieved by point positioning with NNSS TRANSIT doppler satellite receivers.

## NEW DEVELOPMENTS

The team of scientists and engineers who developed the MACROMETER 1000-Series systems are under long term exclusive contract to Aero Service to continue the development of GPS applications technology. This group works closely with Aero's R&D and Operations staff to ensure that focus is maintained on those tasks and projects which will engender maximum practical benefit from new hardware, software, and the use of GPS signals for new positioning and surveying applications.

Dual Frequency System. Dual frequency systems which receive both $L_1$ and $L_2$ GPS frequencies are needed for very precise work over long baselines. Measurements using both frequencies can be utilized to remove much of the error caused by local variability and refraction in the ionosphere.

Aero Service is currently developing prototype commercial dual frequency receivers for those users requiring the highest order of accuracy over long baselines. Early prototype receivers have been used for limited baseline observation tests. The baseline between the Haystack Observatory in Westford, Massachusetts and the U.S. Naval Observatory Timing Station in Richmond, Florida (2045 km) was measured and a root mean square (rms) of the residuals of the doubled differenced observations of 1-2 cm was obtained after adjustment of various parameters. (Bock et al, 1984a)

Prototype commercial dual frequency MACROMETER systems will be available for tests in early 1985 with production equipment to follow as soon as final tests are complete. It will also be possible to obtain retro-fit kits to upgrade existing single frequency V-1000 units to dual frequency capability.

Field Unit Capability. Software enhancements are currently under way which will allow the field supervisor to perform all pre-observation programs and calculations on-site. In the past, observation almanac files were generated on a P-1000 Date Processor (generally in the office) and transmitted to the field party prior to making that particular observation. The ability to make these almanac tapes and satellite visibility files directly on the V-1000 Field Unit will greatly enhance the flexibility of the units and will allow the field supervisors to make maximum use of their resources.

Prototype software modules offering this feature are currently being tested. These units will be available for sale to upgrade existing V-1000 units by early summer of 1985.

## CONCLUSION

The MACROMETER Interferometric Surveying System is currently a viable method of achieving accurate survey results. It is particularly applicable in situations where inter-station line of sight is difficult to achieve and/or highly accurate results (1:100,000 or better) are required. The system is also applicable to lesser order surveys such as those required for mapping and construction projects when existing control is limited in the project area and when difficult line of sight conditions will generate significant problems with conventional survey.

Surveys using MACROMETER interferometric systems will continue to become more cost effective as the GPS satellite constellation becomes more complete during the next four years and as the equipment continues to improve and take advantage of new technology advances.

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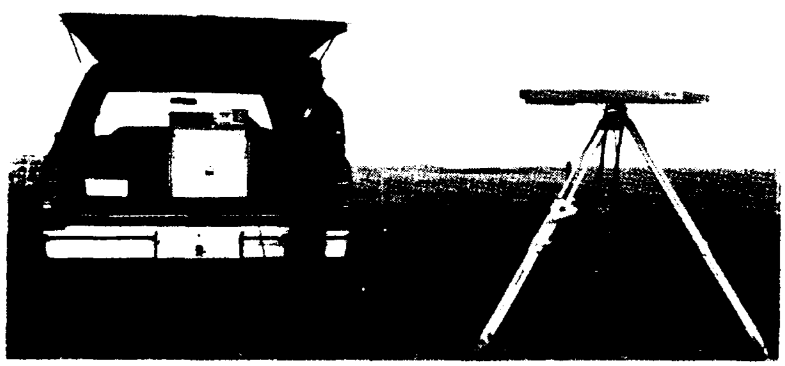


Figure 1. Typical field installation of MACROMETER V-1000 Field Unit.

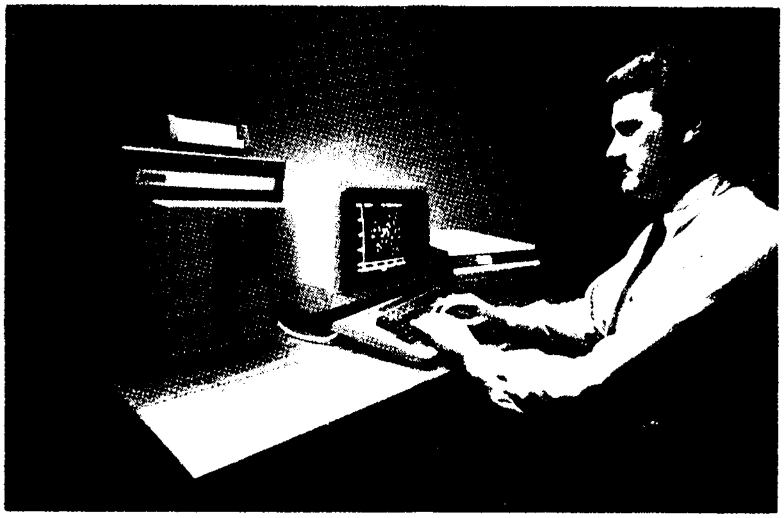
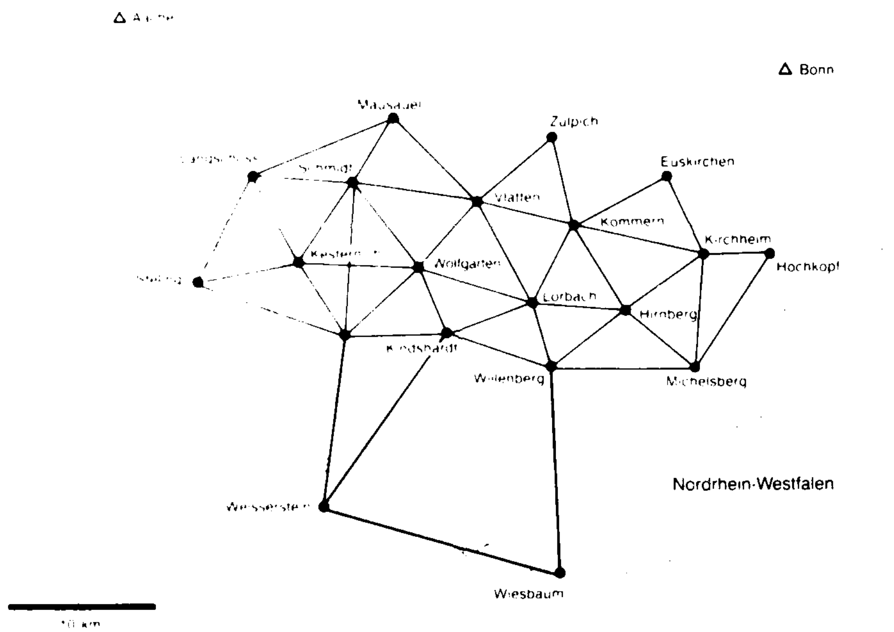


Figure 2. MACROMETER P-1000 Data Processor




**The Eifel Network**

Figure 3. Survey Network in Eifel region of the state of Nordrhein-Westfalen, Federal Republic of Germany, surveyed in September 1983 with MACROMETER V-1000 Interferometric Survey Systems.

# VERTICAL RELIABILITY OF THE GLOBAL POSITIONING SYSTEM

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## BIOGRAPHICAL SKETCH

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## ABSTRACT

The Global Positioning System (GPS) has been introduced as a useful tool for the surveyor. Its capabilities to establish horizontal positions relative to a national network has been documented throughout the past couple of years. Many projects have been completed in the past year consistently yielding 2nd order, or better, results. [At present the instrument most widely used is the MACROMETER TM Model V-1000 Interferometric Surveyor. The firm providing contract services has been GEO/HYDRO, Incorporated, of Rockville, Maryland.] The ability to determine elevations relative to the National Geodetic Vertical Network (NGVN) with GPS has not been as thouroghly documented as its positioning capabilities. Some testing has been done, with good results, indicating its ability to transfer ellipsoidal elevations from one point to another, however, little has been done to relate the transfer of ellipsoidal elevations to the National Network.

This paper describes a test performed near Chincoteague Island, Virginia, to test the validity of using the GPS to determine the NGVD elevations of benchmarks on a barrier island which would not normally be accessible to conventional levels.

## INTRODUCTION

The Norfolk District has an extensive network of Federally maintained channels through the barrier islands on the Eastern Shore of Virginia. In order to accurately survey these channels we have operated a series of tide gages to determine the Mean Low Water, (MLW) at any specific channel.

This program has been performed in cooperation with the National Ocean Service with the end result being a N O.S. MLW referenced to a series of bench marks set in the vicinity of the tide station. Because these marks are only accessible by boat it is impossible to accurately relate their tidal elevations to the NGVN with conventional techniques.

In 1984 the U.S. Army Engineer Topographic Laboratories (ETL) offered to provide a field demonstration of the GPS thru a contract with Geo/Hydro. We took this opportunity to test the systems ability to derive NGVD elevations of bench marks previously placed on a barrier island on the coast of Virginia.

Test Setup

The area selected to perform the test is near the town of Chincoteague, Virginia. A series of tidal benchmarks had been established on the southern end of Assateaque Island. These marks are approximately 7 miles from the mainland, however, it was possible to establish NGVD elevations on them with conventional levels because of a causeway leading to the island.

The National Geodetic Survey had previously established a line of first order elevations down the Eastern Shore with a spur line running across the causeway to Assateaque. Several first order bench marks were within about 1 mile of the Tidal benchmarks on the island. When we established the tidal BM's we also established NGVD elevations on each one. There were a total of 5 BM's set. The levels were 2nd order 1st class.

The GPS determines the position of an unknown point by measuring the difference in position between two recievers, one of which is on a known position. The positions are 3 dimensional and relative to orbiting satellites. Therefore all calculations are on a mathematical model of the earth's surface referred to as an ellipsoid, see figure 1. Therefore the GPS receivers were required to occupy benchmarks with known elevations in conjunction with those on Assateague. Therefore the NGS level line down the mainland was used as a basis for all measurements, conventional and GPS.

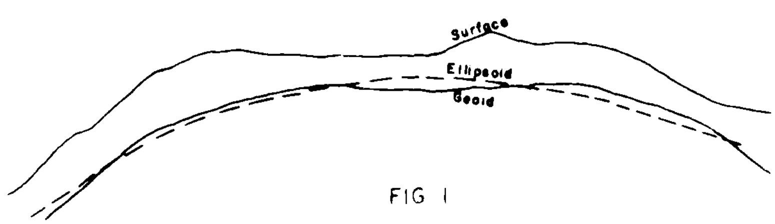


FIG 1

The control for the GPS survey was all first order benchmarks on the mainland of the Eastern Shore. They were R23, E422, and S421. In addition a 2nd order station "Tidal BM2" was used. However, the GPS receiver experienced a malfunction while occupying this station, therefore, the data from this mark will not be presented. Figure 2 shows the test area and the control used.

## Processing

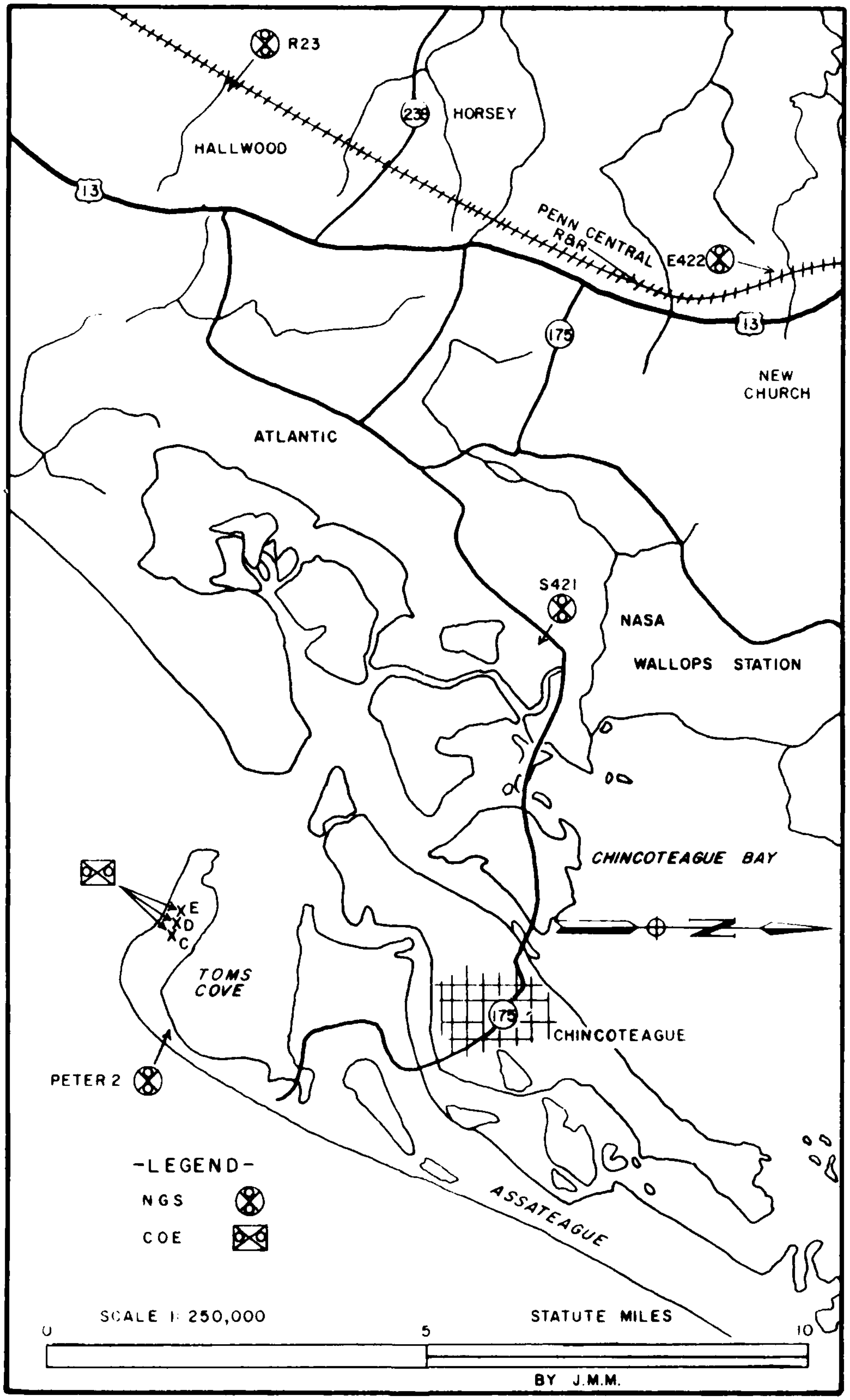
Because the NGS had established first order elevations near a Coast Guard Base on Assateaque Island we did not have to run conventional levels from the mainland. First we checked between four of the NGS marks at the Coast Guard Base. The differences in elevation between each of these marks agreed with the published information to within tenths of a milimeter. Therefore the published elevation of Bench Mark "Peter 2" was held fixed and a line of levels was run down the beach to establish Geoidal elevations on our Tidal Benchmarks. All levelling and adjustments were performed to 2nd order 1st class standards as specified in the Classification Standards of Accuracy, and General Specifications of Geodetic Control Surveys.

The NGVN is established through an extensive program of conventional spirit levels. Therefore all published elevations are referenced to an equipotential surface referred to as the Geoid. The Geoid has an irregular surface but because it is an equipotential surface the pull of gravity is always normal to it. Because it is irregular it is difficult to perform mathematical calculations relating to its true shape. Therefore a surface called the ellipsoid is used for most computations including those relating to the positions of the GPS receivers (figure 1). Therefore the GPS can only determine differences in ellipsoidal elevations from point to point. To determine geoidal (NGVD) elevations with the GPS a model of the relationship between the geoid and ellipsoid must be created. The model used by Geo/Hydro consisted of a least squares fit of the ellipsoidal vs. the geoidal data.

A north-south, and east-west tilt of one surface with respect to the other and a vertical shift was computed using:

$$\text{Correction} = A x + By + C$$

Where A and B represent the angles between the two surfaces
x and y are the northing and eastings
and C is the shift between the two surfaces.


R23
HORSEY
238
HALLWOOD
13
PENN CENTRAL R&R
E422
175
NEW CHURCH
ATLANTIC
S421
NASA
WALLOPS STATION
CHINCOTEAGUE BAY
E
D
C
TOMS COVE
175
CHINCOTEAGUE
PETER 2
-LEGEND-
NGS
COE
ASSATEAGUE
SCALE 1: 250,000
STATUTE MILES
0
5
10
BY J.M.M.
FIG. 2

## Results

To determine the elevations on the Tidal Benchmarks, (C, D and E), three seperate computations were made.

Case 1 - All points of known geoidal elevation were used, including Peter 2. This adjustment should give the best results because Peter 2 is actually on Assateaque Island close to the Tidal Marks.

Case 2 - Benchmarks E-422, S-421, R23 and Tidal BM2 were held fixed and the elevations C, D, E and Peter 2 were computed. There was an apparent malfunction of the unit on Tidal BM2 therefore this data set will not be discussed.

Case 3 - Benchmarks E-422, S421, and R23 were held fixed and elevations for all other marks were computed. This case is the most reasonable to be considered a test because all the fixed points are on the mainland and the unknowns are on the barrier island, except Tidal BM2.

Figure 3 shows the relationship of the individual benchmarks to each other.

The following table lists the results of case 1 and 3.

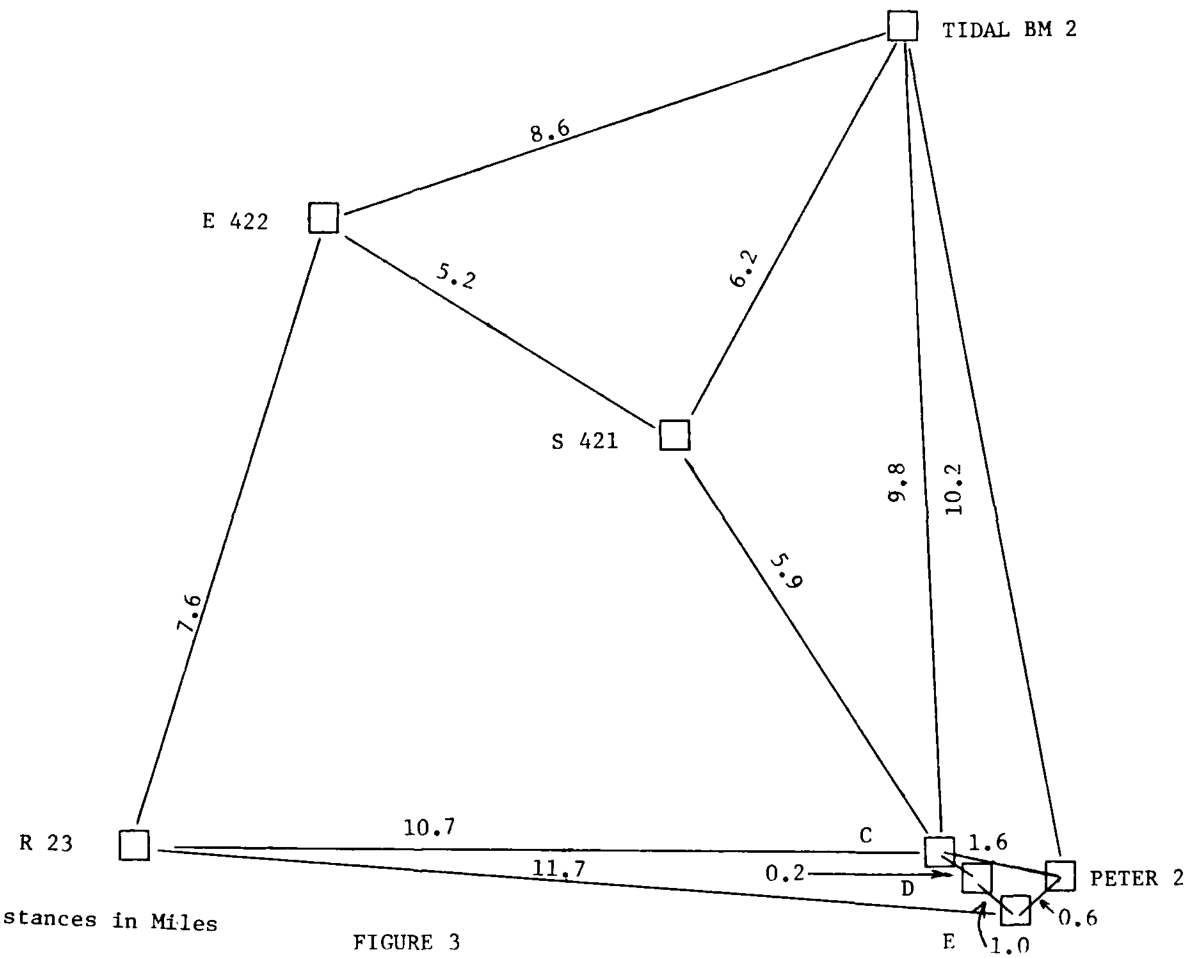
CASE 1

| STATION | OBSER GPS ELEV METER | ADJUST GPS ELEV METERS | DIF ELEV GPS-SPIRIT METERS | SPIRIT LEVELS NGVD | ERROR MM |
|---|---|---|---|---|---|
| E-422 | 7.158 | 6.853 | 0.302 | 6.856 | - |
| S-421 | 6.679 | 6.470 | 0.209 | 6.470 | - |
| C | 1.700 | 1.591 | 0 | 1.6059 | 15 |
| D | 2.033 | 1.927 | 0 | 1.9373 | 10 |
| E | 2.865 | 2.777 | 0 | 2.7913 | 14 |
| PETER 2 | 1.330 | 1.248 | 0.081 | 1.2491 | - |
| R23 | 5.585 | 5.308 | 0.279 | 5.306 | - |
| TIDAL BM2 | 1.192 | 0.990 | 0.204 | 0.9876 | - |

CASE 3

| STATION | OBSER GPS ELEV METER | ADJUST GPS ELEV METERS | DIF ELEV GPS-SPIRIT METERS | SPIRIT LEVELS NGVD | ERROR MM |
|---|---|---|---|---|---|
| E-422 | 7.158 | 6.856 | 0.302 | 6.856 | - |
| S-421 | 6.679 | 6.470 | 0.209 | 6.470 | - |
| C | 1.700 | 1.586 | 0 | 1.6059 | 20 |
| D | 2.033 | 1.922 | 0 | 1.9373 | 15 |
| E | 2.865 | 2.771 | 0 | 2.7913 | 20 |
| PETER 2 | 1.330 | 1.242 | 0 | 1.2491 | 7 |
| R23 | 5.585 | 5.306 | 0.279 | 5.306 | - |
| TIDAL BM2 | 1.192 | 0.994 | 0 | .9876 | 6 |

*25.4mm = 1 inch




* Distances in Miles

FIGURE 3

In case 3 where the Geoid/ellipsoid model was fully utilized the error of 15-20mm is within 2nd order class I standards. Where Peter 2 is used the effective distance for the transfer of elevations is greatly reduced however the vertical error is not reduced proportionately. Therefore for this short distance the error of closure does not meet the published standards. It should be noted that the standards of accuracy published by the Federal Geodetic Control Committee apply directly to conventional surveying techniques and there application to satellite surveying techniques should be performed carefully.

The time and cost to establish NGVD elevations on Assateaque Island from the mainland were basically the same for both systems. However the primary purpose of this test was to determine the potential of the GPS receivers to establish NGVD elevations in areas not accessible by conventional techniques.

## CONCLUSIONS

The method used by Geo/Hydro to model the Geoid/Ellipsoid assumes they are planes with some separation and inclination to each other. This will work well in coastal areas or relatively short distances however this technique should not be generalized. Geoid undulations over long distances or near mass anomalies would degrade the model to the point where it would become useless. There are however other methods available to the Geodosist to determine the shape of the Geoid which would be appropriate for many projects.

This test did succesfully demonstrate the ability to establish 2nd order Geoidal elevations on tidal benchmarks not accessible by conventional techniques. The Global Positioning System holds great promise to be another valuable tool for the surveyor.

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# SPECIFICATION FOR GPS SURVEYS

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## ABSTRACT

The MACROMETER Interferometric Surveyor has been in use for about two years. Based upon this experience, the author presents his views on the specification needed to ensure that the proper accuracy is achieved using GPS systems.

## INTRODUCTION

Since GEO/HYDRO, INC., first introduced the V-1000 MACROMETER instrument in January 1983, this firm has established approximately 1,000 high-order survey points for a host of clients. Additionally, the National Geodetic Survey (NGS) has established a large number of high-order control points with their three instruments. GEO/HYDRO personnel have worked closely with NGS personnel in arriving at a set of operating principles which will eventually be published (by NGS) as a set of specifications.

Although practically all GPS geodetic surveys to date have been performed with the MACROMETER instrument, the general specifications are valid for other systems such as the TI 4100 and the GPS Land Surveys Model 1991.

## NON GPS PHYSICAL SPECIFICATIONS

The most elementary specification for both conventional and nonconventional surveys is to describe the physical conditions of the actual occupation. The NGS requires that this information be submitted in a specific digital format before they will publish it, but the principle should be the same for an client.

Mark: A description of the mark occupied should be given. For example, CoE form 977 provides a good format for this information.

Setup: The NGS has developed a good GPS Observation Log which has spaces for most data required. The NGS observation log shows a picture of the antenna and the observer is required to record the height constants associated with that particular antenna and tribrach. GEO/HYDRO also records the type of tribrach used since each type has a different height constant. We also require that the variable height be measured with a tape in both meters and feet as a check on the measurement. It may sound quite unimportant, but logging an incorrect height has been the greatest source of error in the past two years of GPS surveying.

Time: It is good practice for each observer to have a digital watch that is set to universal time. The starting time and ending time should be recorded on the observation log. Also the time of anything unusual noted during the observation should be recorded. For GPS surveying time should be specified as Greenwich Time (CUT) to avoid misinterpretations.

Weather: Although the weather conditions do not effect the accuracy of the results, at least for translocation surveys, it is probably a good idea to record the temperature, humidity, and barometric pressure for first-order surveys.

Miscellaneous: The serial numbers of instruments used, observers, and other ancillary information should be recorded. It is good practice to make a sketch of the mark and a sketch of the station site.

## GPS SPECIFIC REQUIREMENTS

There are two specific criterion for performing GPS surveys: (1) the length of observation, and (2) the geometric configuration of the satellites at the time of observation. These two factors vary somewhat with the equipment used, so a brief discussion of the various techniques will be given.

All GPS satellite surveying systems that are used for accurate geodetic surveying (better than ± 1 meter) use the translocation method. This method essentially transfers the coordinates from a known geodetic point to an unknown point when both points are occupied simultaneously by GPS instruments. This method is also known as relative positioning.

**Pseudo ranging:** This is the basic satellite technique which is based upon the classical intersection method. Since the X, Y & Z (space) coordinates of each satellite are known (or can be computed) from the ephemeris data, the coordinates of a point on the earth can be determined by measuring simultaneous ranges to four satellites. The errors or uncertainties in the satellite positions cause a nearly identical error in the (earth) surveyed point when only one receiver is used (point positioning). For this reason, the translocation method is used and the difference in coordinates between a known and unknown point are determined. The errors in the satellite's position are minimized by using two receivers to range to the satellite.

Pure ranging to each satellite can only be performed when the earth receiver (GPS instrument) has a clock set to the exact time used by the satellites. This procedure is not generally used (for economic reasons) and the clocks in the two GPS instruments keeps exact relative time which, in general, is offset from the satellite time. This time offset between satellite and receiver time is carried as an unknown in the solution along with the difference in X, Y, and Z coordinates. When ranges to four satellites are observed, four unknowns can be determined.

**Interferometry:** Radio Interferometry is a technique that has been developed by radio astronomers to measure accurate intercontinental vectors using signals from Pulsar stars. This same technique is used by the MACROMETER instrument except the GPS broadcast signals are used instead of the Pulsar stars radio waves. The MACROMETER measures the phase of the (20 cm) carrier wave at each end of the vector (line) being measured. These received phases can be intercorrelated since the time of both receivers has been carefully synchronized (in practice it can also be solved for). The instantaneous (any single) phase difference is a fraction of the 20 centimeter carrier wave length. This instrument can not tell from any single instantaneous phase how many whole (integer) phases or phase differences there are between the point(s) and the satellite(s). This uncertainty is overcome by accumulating a series of consecutive phase measurements while the satellite traverses a (significant) arc of the sky. In effect there is only one vector length that will satisfy the observed phase differences. When three or more (with one in different orbital plan) satellites are observed the three

(spatial) components of the vector can be uniquely determined. A full explanation of this method is contained in a doctoral dissertation by Dr. Benjamin W. Remondi entitled, "Using the Global Positioning System (GPS) Phase Observable for Relative Geodesy: Modeling, Processing, and Results".

The reason for explaining the two techniques is to lay the groundwork for a discussion on GPS specifications.

Pseudo ranging equipment such as the TI 4100 and the GPS Land Surveyor Model 1991 can determine a point's relative coordinates in a matter of minutes. Aside from instrumental errors, there are two major factors that effect the performance of the equipment: (1) the geometric distribution of the observed satellites, (2) the ionospheric effects. The geometric distribution of the satellites observed can be predicted in advance by performing a simulation. Simulations impose "typical" measurement noise on the theoretical measurements to determine the accuracy of points being surveyed. The differential effects of ionospheric inequalities are minimal on lines ten miles or less in length. For lines greater than ten miles in length, the differential effects of the ionosphere can be minimized by averaging observations over a period of time (for single frequency instruments). When dual frequency instruments are used, the effects of the ionospheric inequalities can (theoretically) be corrected. A third smaller correction due to inequalities in the troposphere can be made, but evidence to date shows this effect is insignificant under normal weather conditions.

In summary, the MACROMETER type instruments require a fairly long observation period to:

1. resolve the integer phase biases
2. cancel the ionosphere effects.

One the contrary the pseudo ranging instruments such as the TI 4100 and GPS Land Surveyor resolve ambiguities in a matter of minutes and obtain an increase in accuracy with the length of the observation period.

In practical terms, if sufficient observations are made with a MACROMETER instrument to resolve the ambiguous phase biases, a sufficient number of observations will be taken to cancel the random ionosphere effects.

In rather general terms, Table 1 gives the accuracies obtainable with various length of MACROMETER observations for a ten kilometer line.

| Accuracy | Either end of "Window" | Mid. Portion of "Window: |
|---|---|---|
| First | 120 minutes | 90 minutes |
| Second | 90 minutes | 60 minutes |
| Third | 60 minutes | 45 minutes |

TABLE 1

The values in Table 1 are only estimated and are based upon experience obtained over the past two years. a simulation or actual observation will, naturally, provide more exact information concerning accuracy, for a specific set of conditions.

The printout of the MACROMETER solution provides two accuracy indicators; these are the Chi square number and the uncertainty in latitude, longitude, and height. The Chi squared value should approximately equal the number of observations and should rarely exceed twice the number of observations. It can be generally observed that high Chi square values in a given solution will also yield higher than normal coordinate uncertainties. It should be noted that acceptable solutions have been obtained which have yielded high (more than two times) the expected Chi square.

The uncertainties of the latitude, longitude, and height given on the MACROMETER printout are basically the formal standard error of the solution. The values of these (formal) coordinate uncertainties were compared with the values given by a least square solution for 80 lines ranging from three miles to twelve miles. In general, the two sets of values (formal and actual uncertainties) agreed rather well. In fact, the uncertainties listed on the MACROMETER printout appeared to be closer to the 90% error than the standard error on the case investigated.

The surest way to ensure that accurate observations are obtained is to have the GPS survey firm provide a proposal which contains the following information:

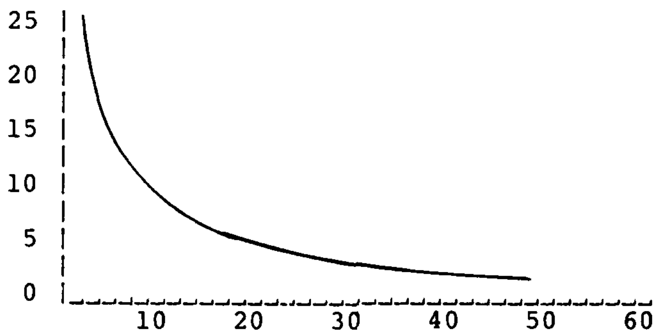
1. Which satellites will be observed and for how long.
2. A simulation or test results under similar conditions which demonstrates accuracy.
3. The simulation should provide how many observations and a range of acceptable Chi squared values.
4. Which ephemeris data will be used, i.e., private source, DoD, Broadcast.

If this information is provided and the field results are within the specified limits, you can be confident of good results.

## PSEUDO-RANGING EQUIPMENT

The TI 4100 and GPS Land Surveyor do not require the same length of time to achieve second-, and third-order accuracies that the MACROMETER instrument requires. The reason for this is that these instruments are capable of resolving the ambiguity in the vector directly; whereas, the MACROMETER relies upon accumulating a large number of observations.

Little has been published about the TI 4100, but it should operate essentially in the same manner as the GPS Land Surveyor. Basically these instruments can obtain an unambiguous position in a few minutes of observation; however, the accuracy is improved in time as shown in Figure 1.




Time of Observation in Minutes

FIGURE 1

This figure shows a typical Gaussian distribution. As can be seen the accuracy improves rapidly at first and then become asymptotic the length of time increases.

Figure 1 does not apply for lines over about 10 km in length where the accuracy decreases due to the ionospheric effects. This ionospheric effect can be minimized by observing for longer periods of time.

Accuracies of the pseudo-ranging equipment do not depend upon a minimum observation period (i.e., one hour for MACROMETER); however, the accuracy obtained is a function of the geometric distribution of the satellites. The accuracies shown in Figure 1 are for the best mid-portion of the satellite "window" of opportunity. When observations are made either early or late in the window, a longer observation is required to obtain the same accuracy.

Specifying a given order of accuracy for pseudo-ranging equipment is slightly more difficult than for instruments like the MACROMETER; however, proposals which contain test results and other substantiating data (i.e., simulations) should give a clear indication of the achievable accuracy. Present plans call for the GPS Land Surveyor to be tested in late February by the FGCC so that more substantive information on this instrument should be available in the near future.

GEO/HYDRO plans to conduct comprehensive tests with the GPS Land Surveyor over points separated by varying distances and for observations over a wide range of time. The results of these tests will also be reported in the technical literature in the future.

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GPS Land Surveyor™ is a trademark of GPS Services, Inc.

TI-4100™ is a trademark of Texas Instruments.

# SESSION XI: PHOTOGRAMMETRY

# BIOGRAPHICAL SKETCH

## PHOTOGRAMMETRIC MAPPING AND MONITORING OF THE MANASQUAN INLET AND DOLOSSE

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David K. Nale is a Certified Photogrammetrist and President of Aerial Data Reduction Associates, Inc. He received his degree in Earth and Mineral Sciences from The Pennsylvania State University and his Masters in Business Administration from LaSalle College. He has been project manager of over 300 major environmental, industrial and political mapping projects. He is past president of the Council of Practicing Photogrammetrists, and a past director of the North Atlantic Region of the A.S.P., as well as a member of ACSM and several State survey organizations.

## ABSTRACT

Manasquan Inlet is located on the Atlantic Coast of New Jersey, approximately 26 miles south of Sandy Hook, and provides a connection from the New Jersey Intracoastal Waterway and Manasquan River to the Atlantic Ocean. To stabalize the location of the inlet and counteract the erosional effects of coastal storms and long shore current concrete jetties were built to protect the sea channel thru the inlet. To further protect the jetties from the surf, eleven foot, 16 ton concrete interlocking dolosses were placed around the jetties. The project described below is a part of the Manasquan Inlet Monitoring Program. Manasquan Inlet is one of nine coastal projects in the United States selected for detailed monitoring under the Corps of Engineers Monitoring Completed Coastal Projects (MCCP) Program.


## INTRODUCTION

After the rubble mount and concrete capped jetties were in place at Manasquan, over 650 dolosses were positioned around each jetty for protection. Extreme care was taken during placement to insure that the dolosses were interlocked with each other. Scuba teams were utilized underwater as the 16 ton dolosses were gingerly placed into position.

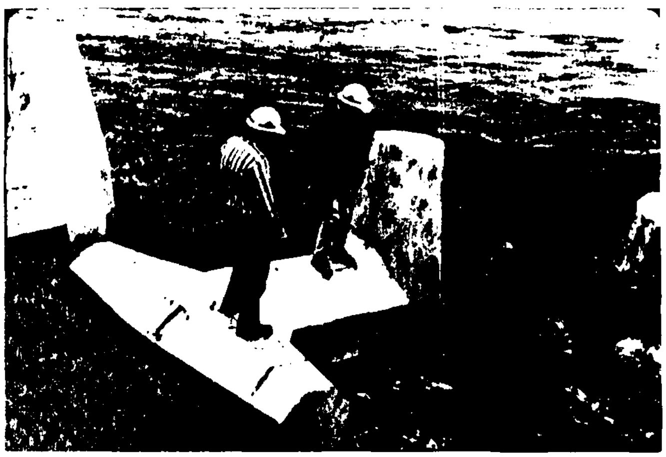

Figure 1: 16 Ton Dolos

The question that faced the Corps of Engineers at this point was, how do we effectively monitor the position of the dolosse to insure that they have interlocked and that wave action is not causing displacement of the dolosse?

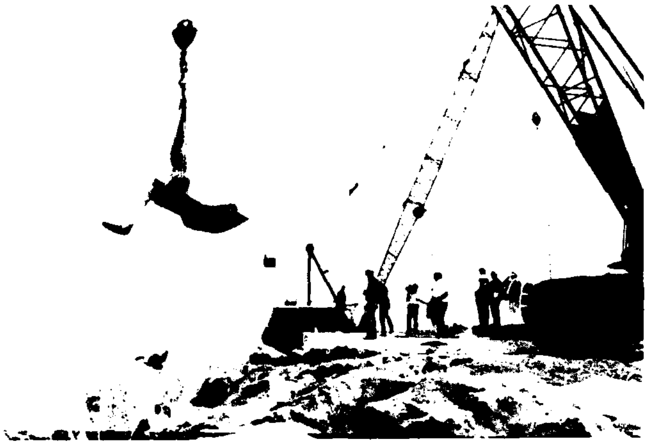

Figure 2: Placement of Dolos

After glancing at Figure 3 it becomes readily apparent that the use of traditional survey methods for this task would almost be physically and economically impossible. In the Spring of 1982, the Corps of Engineers considered the possibility of employing precision photogrammetric methods to aid in the monitoring process.

Figure 3: Dolos In Position

Since the dolos survey must be accomplished again and again over the years, it was of prime consideration to design a photogrammetric approach that would be economical, quick and above all, accurate. Considerable importance was given to the repeatability of the methods.

AERIAL PHOTOGRAPHY

A major problem faced by the land surveyor employing traditional field survey methods was determining exactly what dolos he would be measuring and how to physically view

all of the dolosse. Aerial photography, however, permitted a means of accurately recording each dolos at low tide for both jetties within an instant.

Tide charts were employed to target the most desirable days for flying, i.e., days which low tide occurred at the highest sun angle. A series of possible flying days were selected with the actual flying day to be chosen dependent on weather and visibility conditions.

On January 5, 1982, a twin-engine Cessna 320 was aligning itself on a pre-determined flight path over the beaches of Manasquan, New Jersey. In less than a minute, both of the jetties and all 1300 dolosse were captured on film, utilizing a Zeiss RMK A 15/23 mapping camera. The flight altitude was 600 feet above Mean Sea Level(MSL), and the film utilized was Kodak Double X Aerographic Film. Standard 60% forward lap stereo photographs were obtained.

Since precise positioning of the dolosse within 10ths of a foot was critical, care was taken by the photogrammetrist to employ the most precise of aerial cameras available. Calibration certificates were carefully studied prior to selection of a camera.

## GROUND CONTROL SURVEYS

Geodetic control surveys were performed by the photogrammetric contractor. The horizontal datum was of local origin. The vertical datum was based on Local Mean Low Water (LMLW), Manasquan Inlet. Bench marks in the vicinity were furnished by the Corps of Engineers. An HP-3808 EDM, Wild T-2, and Wild NA 2 Self Leveling Level was used for precision control extension. Prior to the flight, small 1' x 1' black control targets were painted on the jetties for photo identification of control points.

Extreme care was taken during the control survey to reduce random error to a minimum.

## STEREO PHOTOGRAMMETRIC COMPILATION

The photogrammetric mapping was compiled on a Kern PG2-AT stereo restitution instrument, interfaced with a DC2B digitizing graphic enhancer. The mapping was compiled at a scale of 1" = 5' (20X over negative scale). The initial mapping of each jetty included the compilation of the jetty and all visible dolosse. No contours were compiled. Spot elevations were recorded on the concrete jetty cap and on all visible corners of all clearly defined dolosse. Special attention was paid to recording as many dolosse as possible along the water's edge. (The area that one would expect to be most significantly affected by wave action.)

Figure 4: Manasquan South Jetty From The Air

The stereo compilation of such irregular objects as dolosse was by no means a routine task. Only the most qualified photogrammetrist were utilized as stereo-plotter operators. The operators expressed concern about their ability to precisely record each of the dolosse. It was the certified photogrammetrist's opinion, however, that the precise definition of each dolos was not as important as was the placement of spot elevations on the arms of the dolosse. It was his opinion that horizontal shifts in the magnitude of 6" could be detected, and that the vertical component of the horizontal shift could be measured within 2/10 of a foot. The initial mapping of the south jetty was completed on March 26, 1982.

On January 29, 1983, a second photo mission was completed. The same Zeiss RMK A 15/23 mapping camera was utilized. The camera was mounted in the same aircraft and the flight crew was the same. It was the intention of the photogrammetric contractor to keep all possible error which might be caused by the use of different equipment to a minimum. The same photogrammetrist and stereo restitution instruments which were used on the initial mapping were employed for the compilation of the comparison mapping.

A second map of the Manasquan south jetty and dolosse was compiled. The map was compiled totally independent from the initial mapping. The first and second map were then physically overlaid to each other. The ground control positions were used for registration.

An examination of the overlayed maps revealed no measurable movement in all but three of the dolosse. The movement in those three dolosse, however was significant. The three dolosse were located side-by-side and initially interlocked with each other. It is the opinion of the photogrammetrist that one of the dolos shifted causing the trio to topple

## CONCLUSION

A debriefing of the photogrammetric compilers was conducted by Jeffrey Gebert of the Philadelphia District of the Corps of Engineers and James Clausner and Mary Vanderheyden of Coastal Engineering Research Center (CERC), and David K. Nale, principal of the photogrammetric firm contracted to undertake the Study.

It was generally concluded that due to changes in sun angle and water elevation, a random noise error could be expected in the magnitude of 3/10 of a foot, both in horizontal and vertical position. Because of the very irregular shape of the dolosse comparison measurements of less magnitude were difficult to ascertain. However, an analysis of mapping reflected a very slight overall settlement in the jetty and dolosse towards the seaward end.

A recommendation was expressed by the stereo compilers to place small 6" cross type markers randomily on the dolosse, either during or initially after placement. It was their feeling that these targets would assist in the exact determination of horizontal position and in eliminating error caused by the mapping of the irregular shaped dolosse.

# ACQUIRING AN APPS-IV AND SETTING UP AN ALL DIGITAL SURVEY SYSTEM

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## BIOGRAPHICAL SKETCH

Marvin W. Taylor has BS degrees in Geology from Iowa State University, Civil Engineering from University of Nebraska, and a Masters of Business Administration from Creighton University. He worked for an Omaha Architect/Engineering firm before joining the Corps. He has worked in Construction Division (Supervision and Inspection Branch) and Engineering Division (Foundations and Materials Branch) before becoming Chief of the Surveys and Mapping Section in 1980. Mr. Taylor is a member of ACSM, SAME, and a Professional Engineer in his home state of Nebraska.

## ABSTRACT

The Omaha District has recently acquired an APPS-IV. An APPS-IV is a desk top medium accuracy (10 microns) photogrammetric analytical stereoplotter and several accessory pieces of equipment. The APPS started out as military hardware but can be used for many other applications. The APPS will be able to project computer data into the operator's view so that the data overlays the photographic images. There are endless uses for this machine in all the different kinds of work the Corps of Engineers does.

The equipment and acquisition is discussed. The APPS with stereographic superposition along with a CRT terminal and color graphics terminal is one work station. Two color graphics work stations and a CRT terminal with printer were acquired. The only problem in the total acquisition process was the communications line to the remote computer.

Digital land surveys using EDM, data recorders, and computer plotted drawings and digital hydrographic surveys are briefly discussed. The plans are to learn each new system (APPS and digital land surveys) before integration of all three is started.

## INTRODUCTION

The Omaha District manages about 1,300,000 acres of land on more than 30 major projects and 60 minor projects, works regularly on more than 20 military bases and, as the phrase says, "performs other duties as assigned." Our active navigable river responsibility covers about 250 miles, with survey responsibility extending to the full navigable Missouri River (750 miles). Our normal civil area encompasses area in nine states, and our normal military area reaches into seven of the civil states and two other states. Keeping all the data under control and all personnel using the same data is difficult. The various

components and systems talked about in the paper can aid greatly in acquiring, keeping, and updating various kinds of map-based data used to carry out our District's assigned functions.

## WHAT IS AN APPS-IV?

APPS is an acronym for Analytical Photogrammetric Processing System. APPS-I is the field military version and the first model developed. APPS-II and -III were research and development models. APPS-IV is the model being manufactured and used for engineering uses. The U.S. Army Engineer Topographic Laboratories have assembled the APPS-IV and other equipment into a Computer-Assisted Photo Interpretation Research System (CAPIR). The Omaha District APPS-IV setup (Fig. 1) and ETL's CAPIR are basically the same.

The APPS-IV is a medium accuracy (10 microns) photogrammetric analytical stereoplotter. It has built-in microprocessors (13) to control its own operation and provide a buffer for data transfer. Data can be digitized from photogrammetric images; a stereo pair of images are loaded onto the machine, the appropriate camera data and ground control data must be input, and the photogrammetric solutions derived. Once all the preliminaries are out of the way, points on the images are digitized at the direction and interpretation of the operator. As with any photogrammetric plotter, it is up to the operator to interpret and the machinery just follows the operator's directions. The points are then stored and can be plotted on a drawing and/or analyzed using a color graphics computer terminal.

An APPS-IV may be fitted with a pair of graphics screens that project data into the optics so that the data overlays the images, and to the operator it appears that the data is drawn on the photo images. This is known as graphics superposition. The coordinates are sent from the host computer to the APPS, and the APPS moves the images on the screens around to match the movement of the photogrammetric images.

This capability opens up unlimited opportunities. For geologic interpretation, magnetic data and/or gravity data may be superimposed over the images. For bankline work, one may superimpose previous years' banklines over current images. If the area under study is a reservoir, the boundary line and the estimated future bankline may be displayed to check to see if additional land acquisition is necessary.

Active validation of digitized points, which can greatly speed up the process of converting imagery into electronic media, is another aspect of superposition. When a point is digitized and sent to the host computer, returned to the APPS and projected into the optics so that it can be seen, the operator knows the point is the desired one and is in storage on the host computer.

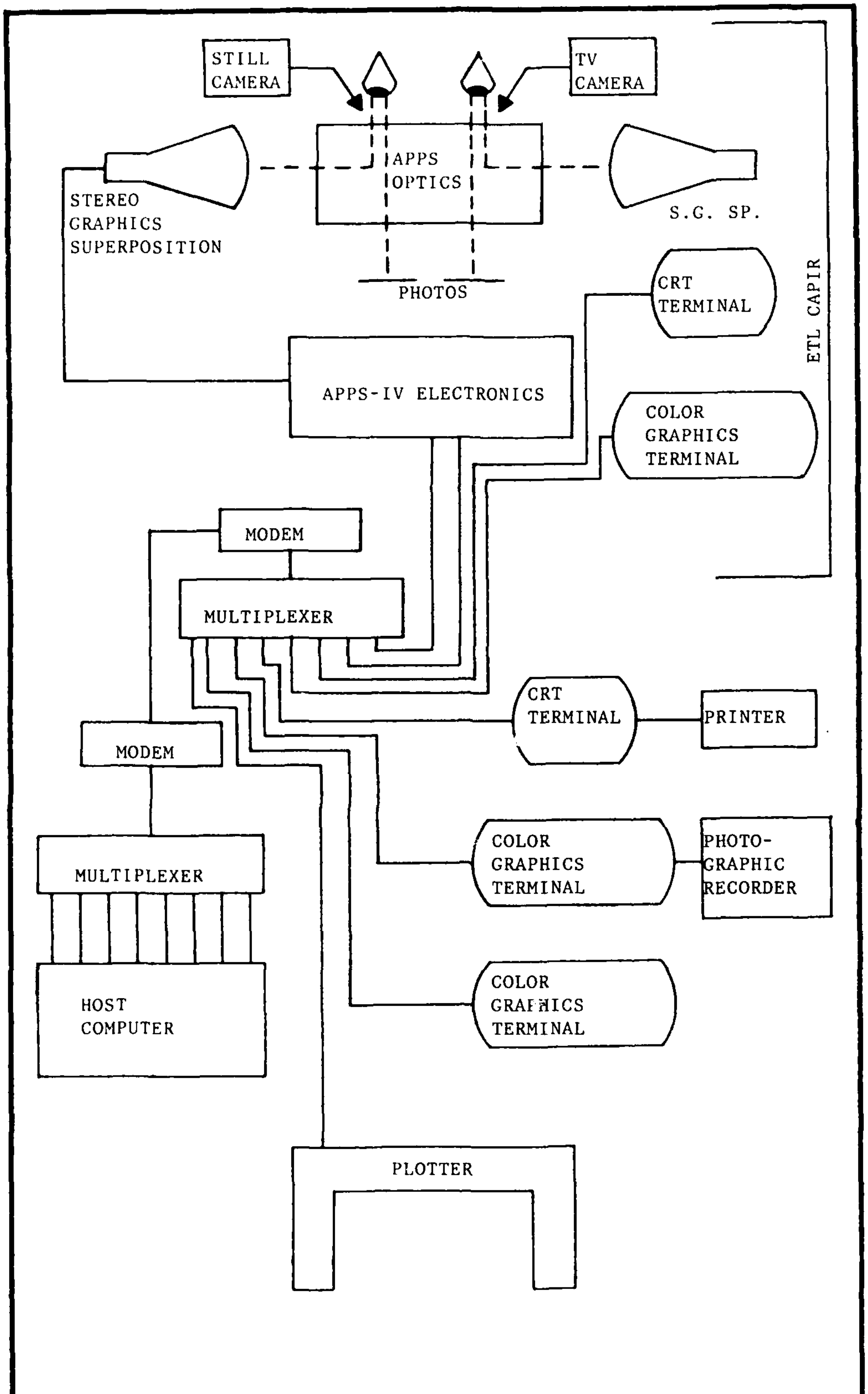


Figure 1 Omaha District's APPS-IV Setup

## BACKGROUND OF APPS

Development began in 1968, when Engineer Topographic Laboratories started investigating using photogrammetric techniques in military survey and mapping operations for the field Army. The initial attempt involved an analog photogrammetric approach which was based upon the use of a three-projector stereoplotter that generated an optical, three-dimensional stereomodel. It was too large, heavy, and required too much time and skill to operate. The Lance Missile personnel were also looking for a simple, rugged piece of equipment that could locate the position of targets. To answer both needs, an analytical concept was developed in 1971 to provide the simplest possible operation by unskilled military personnel in the field. The APPS-I consists of off-the-shelf items plus an interface developed by ETL. It is similar to the APPS-IV in Figure 1, but it is just optics, photo stages, and a microcomputer.

APPS-I has several uses. It will be used by the Artillery to generate data where stereo photographic data exist. The APPS-I and several ancillary pieces of hardware are housed on a 2.5-ton truck.

The Army plans to use APPS-I for determining the position of friendly units and enemy targets. The Navy, after tests with APPS-I on an aircraft carrier for planning strikes against land targets, decided to procure additional APPS-I for all aircraft carriers.

The DMA Aerospace Center has evaluated the system to provide coordinates for Air Force weapon systems. The evaluation was satisfactory, and the Air Force has procured additional systems. The Defense Mapping School and the Corps are evaluating the APPS-I to establish survey control by locating landmarks that can be found and occupied by combat survey personnel. These APPS points could be used as survey control points from which short local surveys could be run to a nearby artillery battery or other user. The Defense Mapping School plans to use a large-scale base to establish ground control accuracy to 1 or 2 meters, which should be sufficient for preliminary construction and engineering topographic surveys. (Bibliography No. 1)

ETL researchers are applying an APPS-IV, accessories, and artificial intelligence theory and technology to photo interpretation. Computer-Assisted Photo Interpretation Research (CAPIR) system provides the primary tool for a broad-based program of feature extraction research. CAPIR represents the first successful interface between the interpreter and computer. Researchers have used the CAPIR system to develop new techniques and technologies to manage digital map data and to explore targeting concepts for the Pershing II project. (Bibliography No. 2)

## APPLICATIONS AND DEMONSTRATION PROJECTS

ETL researchers have assembled the CAPIR (Computer-Assisted Photo Interpretation Research System), as mentioned earlier, to assist trained specialists in developing and updating digital data bases. CAPIR uses analytical photogrammetric equipment, geographic information system software and computer-assisted data analysis and management techniques to input, store, retrieve, update, manipulate, and display geographic and cartographic data.

ETL is performing work under Corps sponsorship to evaluate, demonstrate, and document the potential of CAPIR technology for Civil Works data extraction, development, and updating applications. As part of this effort, three projects have been done. These demonstrations are designed to illustrate how the Corps could use CAPIR technology to improve its assigned responsibilities.

The first of these, with Detroit District (Clinton River), demonstrates the use of CAPIR technology for extracting land use, structure and topographic information used in economic damage assessment models.

The CAPIR system can supply data to the existing HEC/SAM modelling program with previously unrealized accuracy. (Bibliography No. 3)

The Seattle District (Fort Lewis) demonstration was a project showing the use of CAPIR for Corps Military Master Planning. This demonstration consisted of the digitizing of 1967 Master Plan Base Maps, with additional data derived from photography flown in the fall of 1982. All 1967 Master Plan map data was digitized on a digitizing table. The updates were accomplished using the APPS-IV stereoplotter. Outputs included 1967 and 1982 Master Plan maps, building and pavement data for 1967 and 1982, sewer and water, and contour data at 1:4800 scale.

The Portland District (Columbia River) demonstration was a Civil Works project to show the capability of CAPIR in interpretation and digitization of wetland data. Three years (1957, 1974, and 1981) were used for the evaluation of dredging effects on Columbia River wetland habitats. Only photographic data were used in this demonstration, so only the APPS-IV was used for digitizing. This project consisted of the identification and recording of five major wetland classifications. The areas were evaluated from many different aspects to determine the best scheme for displaying these data. The outputs for this project included demonstration maps for each year at 1:24000 and 1:5000 scale. (Bibliography No. 4)

One of the exciting applications of the APPS-IV is preparing a map using control from USGS quadrangles. Imagery, either new or existing, and latitudes, longitudes, and elevations from quads can all be loaded into the APPS and computer. After doing all the calculations and digitizing, a finished map can be produced that will be better than the

quad as far as scale and detail. The quality of the map will be limited only by the scale and quality of the images. This kind of capability will be especially useful at the planning stages of projects where the desired information and detail never match the available funds.

Floodflow cross sections may be obtained using quad control data or normal ground control methods depending upon the desired detail and available funds.

## REASONS FOR ACQUIRING AN APPS-IV

The Omaha District plans to use all the capabilities of the APPS, discussed in the preceding sections, at one time or another. There are a multitude of plotters available, both large machines and desk top. Most do not have the APPS-IV capabilities or require dedicated specialists to operate.

For the projects that cannot justify full-fledged surveys, we will be able to use new or existing aerial coverage and control from quads to produce maps of the area for use on paper and electronic format. The analysis and studies can be speeded up using the computer to do all the mundane measurements. All the plots can be done by the computer also.

Updating of existing mapping can be done efficiently by an APPS-IV. We currently have an area that was mapped a couple of years ago, but the creekbeds have been highly altered. We will take the existing mapping and load in new aerial coverage and compare the creekbeds to the existing maps; where the new contours do not match the old, we can replace the old with the new contours. We will then take aerial cross sections.

Other floodflow cross sections can be taken directly off either new or existing coverage, using either kind of ground control data, from quads or from ground surveys.

The stereographics superposition will be used for bankline line work as mentioned earlier. We have extensive coverage of our reservoirs and rivers. We have coverage of the Missouri River back to the 1930's. We will compare the erosion and our boundary line to check for needed new acquisition. We can superimpose leases or other political or legal lines on aerial images to check overlaps or any kind of potential problems.

Several different groups have interest in the changes in the river. With superposition, we will overlay the data derived from the available coverage and quickly be able to delineate the changes.

We are going to try to check for riprap movement. We have old aerial coverage of riprap with a wide strip painted on the top of the rocks. We will obtain new coverage and superimpose the digitized locations of the strip over the new coverage. This should tell us if any movement has taken place and how much.

We will take the coverage used by contract photogrammetric mapping and be able to check the adequacy and accuracy of the work.

## OMAHA'S CONFIGURATION

The Omaha District Electronic Mapping Center's hardware configuration follows that of the ETL CAPIR system mentioned earlier. The initial hardware configuration is shown in Figure 1 and described below. There are four work stations: a photogrammetric station centered around the APPS-IV analytical plotter; two color graphics work stations for the analysis and display of geographic information; and a reports cathode ray tube terminal for generating hard copy listings. Communications equipment provides a link to the remote computer via a private telephone line.

### Photogrammetric Station

The photogrammetric station is centered around the APPS-IV analytical plotter with stereographic superposition capability. A CRT terminal will serve as the operator's means of giving the computer instructions. A color graphics terminal will display the data during the digitizing. A still camera and TV camera, monitor, and videocassette recorder will be hooked into the APPS-IV, allowing others to see the scene the operator is seeing and record the scene on photos or videotape.

### Graphics Work Station

The graphics work station is based around a Lexidata Model 2410 color graphics terminal. A photographic graphic film recorder (with its own precision CRT) is hooked into one of the graphics work stations. The recorder will photograph the image shown on the work station in various photographic formats.

### Reports Terminal

The reports terminal will include a CRT terminal and printer.

### Communications Equipment

The communication equipment, which is Universal Data System, Inc., statistical multiplexor, funnels all the cables from the equipment into a single line going to a high-speed modem. A companion modem in Ft. Collins, Colorado, and multiplexor breaks into several lines to go into the computer ports. The data line is an AT&T dedicated line.

### Plotter

The plotter is a Hewlett-Packard 7585B Plotter, with eight-pen capability.

**Digitizing Station** (Scheduled for FY 85)

The digitizing station is centered around a precision coordinate table digitizer. It is not shown in Figure 1.

## ACQUISITION

Omaha District first learned about the APPS at this conference in February 1982. A presentation by Jonathan C. Howland of Autometric, Inc., described the APPS-IV and its capabilities. Additional information was obtained from Autometric.

The APPS was submitted as part of the Fiscal Year 1983 Plant Replacement and Improvement Program (PRIP). After approval for the funding, trips were made by Omaha District personnel to ETL and the Department of Interior Fish and Wildlife office in Fort Collins, Colorado, to inspect APPS installations and to talk to the people using the systems. Since acquiring a computer is such a long process, the only possibility for an APPS system was to use a remote computer. Several possibilities were investigated, and the most feasible was to hook up to an existing contractor doing work for the U.S Fish and Wildlife at Fort Collins, Colorado. This type of arrangement for an APPS had never been done, but it seemed feasible. A dedicated phone line would be required with special communications equipment at both ends.

## CONTRACTING

Since the APPS was developed by ETL and Autometric, a sole source contract was initiated with Autometric to supply the APPS and associated equipment. A computer service contract was initiated with Technicolor Government Services in Fort Collins. A request for service was written to AT&T for a private four-wire voice grade line which the intended communications equipment was designed to work with. No problems were experienced with the contract for the equipment or the computer service. But BIG problems were experienced with the phone line.

## PROGRESS

The request for the phone line went in just after the reorganization of the Bell system and AT&T. Due to this reorganization, acquisition took a long time. It took about 8 months after they received the order to get the line. This made the agreed upon schedule between Omaha and Autometric worthless since, without a computer, the expensive equipment will not work. Since a reliable schedule could not be counted on for the phone line, we had to wait until it was actually installed until planning for the delivery of the APPS and the associated equipment.

Since installation of the phone line, the APPS and its associated equipment have been installed and made operable. Training started in January 1985.

## AUTOMATION OF FIELD SURVEYS

The Omaha District has chosen the Wild "Field-to-Finish" system for use in computing, plotting, and storing field survey data such as traverses, cross sections, and angle and distance topography. A complete T-2000 and DI-5 and GRE3 will be acquired for each survey crew. The T2000 is an electronic theodolite. The DI-5 is distance measuring equipment that fits on the T2000, and the GRE3 is the electronic data recorder. A Hewlett-Packard microcomputer and plotter has been acquired for the office. Data transmission over phone lines will be used to obtain data from the outlying offices and work sites. The HP plotter will be used for both systems, the microcomputer and the APPS, to produce drawings.

## HYDROGRAPHIC SURVEYS

While electronic photogrammetric mapping and totally digital field surveys are new to the Omaha District, digital mapping and methods are not. The District has been doing totally computer controlled hydrographic surveys for many years. The District's boats, the THORNTON and DAKOTA, and their associated electronic equipment have been working on the Missouri River for quite some time. The DAKOTA has a sweep system with 16 transducers that is operated by Omaha District personnel for both Omaha and Kansas City Districts. It works from Sioux City, Iowa, all the way down to St. Louis, Missouri, a distance of 750 river miles. The THORNTON has a single sounder system. The boat is only 4 years old; it was custom-built for the task. The electronic equipment is much older, having operated on several boats before being put onboard the THORNTON. The data from the system is run on different computers for analysis and plotting. Both of these systems have been successful in fulfilling their mission.

## PLANS

Since the stereographics will speed up the digitizing process, the biggest time waster will be giving instructions to the computer such as what the operator wants to do or the identification of the point being digitized. Voice commands have been attempted, but this takes some pretty good programming modifications. An alternative that is being explored is to turn an IBM Personal Computer into a dedicated terminal for the APPS instead of the CRT terminal presently being used. Keytronic Corporation makes a speech recognition keyboard that accepts 160 words as commands that appear to the PC as keystrokes. It would be simply a matter of getting a program to turn the PC into a terminal and, with the special keyboard, the operator would not have to look away from the optics. This would make the photogrammetric digitizing process proceed as fast as possible, with absolutely no wasted time.

The plan at the Omaha District is to fully learn each of the new systems and become proficient in their use. After that, integration of the three systems will be started.

## CONCLUSION

APPS technology will aid the Omaha District in carrying out its functions and assignments. It provides new methods to accomplish our work in a more efficient and effective manner.

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COORDINATION OF FEDERAL DIGITAL CARTOGRAPHIC ACTIVITIES

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Abstract

Throughout the Federal Government, applications are emerging for spatial data bases that require digital cartographic data as a framework. This paper is an inventory of major applications of spatial data in the Federal Government. The paper concludes with a discussion of the extent to which these data needs are being coordinated and outines efforts to further coordinate digital cartographic data bases and production in the Federal Government.

BIOGRAPHICAL SKETCHES

Rupert B. Southard is Chief of the U.S. Geological Survey's National Mapping Division. He received his B.S. in Civil Engineering from Syracuse University. In the late 1950's Mr. Southard was engaged in photogrammetic research and instrument development and was involved in the development of the orthophotoscope and early applications of orthophotography. In 1977, he became Chief, Topographic Division and following a reorganization of the U.S. Geological Survey's mapping activities in 1979, he was named Chief of the newly formed National Mapping Division. He is the U.S. representative to the Working Group on Geodesy and Cartography of the International Scientific Committee on Antarctic Research (SCAR), and is Chairman of the Panel on Geodesy and Cartography, National Academy of Sciences, National Research Council (CPR). He has been active in the American Society of Photogrammetry in several positions. From April 1972-March 1973, he served as Department of the Interior representative to the OMB Federal Mapping Task Force. In 1982 he was named Chairman, Interior Digital Cartography Coordinating Committee, and in 1983 he was named Chairman, Federal Interagency Coordinating Committee on Digital Cartography.

John D. McLaurin is the Digital Cartography Program Manager for the U.S. Geological Survey's National Mapping Division. Mr. McLaurin received a B.S. in Civil Engineering and a M.S. in Civil Engineering from the University of Michigan in 1961 and 1965 respectively. He has had several research and management positions with the U.S. Geological Survey including Chief, Rocky Mountain Mapping Center, 1980-1984. Mr. McLaurin is a member of the American Society of Photogrammetry and the American Congress on Surveying and Mapping. He currently chairs the Standards Committee for Automated Management Facilities Management International (AM/FM).

Larry L. Amos is the Digital Cartography Program Coordinator for the U.S. Geological Survey's National Mapping Division. Mr. Amos received his B.S. in Civil Engineering from the University of Missouri at Rolla in 1968, and is registered as a professional engineer in the State of Missouri. He is committee secretary for both the Interior Digital Cartography Coordinating Committee (IDCCC) and the Federal Interagency Coordinating Committee on Digital

Cartography (FICCDC), and currently chairs the Data Production Planning Working Group for the IDCCC. Mr. A¬os is a member of the American Congress on Surveying and Ma.ping.

Eric Anderson is Chief of the Office of Geographic and Cartographic Research in the National Mapping Division of the U.S. Geological Survey. His doctoral studies were completed at Northwestern University. He spent 5 years as a Research Fellow at the University of Edinburgh, Scotland before joining the Geological Survey in 1975. At USGS, he has been involved in the development and application of geographic information systems. Mr. Anderson served as Chief of the Branch of Applications and Digital Cartography Technical Manager before assuming his current position.

## INTRODUCTION

Advances in computer technology and in the mapping sciences are altering significantly the ways in which maps can be prepared, stored, and used. Maps and the information linked to maps because of its relation to physical, administrative or other spatial reference points, areas, or boundaries can be stored in digital form to provide enormous flexibility in preparing needed map products. But more importantly, this new cartographic medium, coupled with advanced spatial data handling techniques is increasing the utility of the data to decisionmakers throughout the Federal Government. New applications of digital cartographic data grew so fast that they quickly outpaced the supply of data. The result is a proliferation of uncoordinated data production activities throughout the Federal Government with many undesirable results. More often than not, data collected for use on one computer system or software package couldn't be used by another without a large 'nvestment in reformatting and restructuring the data and sometimes the data defied all efforts to transfer its use.

Efforts to coordinate Federal digital cartographic activities have grown slowly until 1982 and 1983 when the Department of the Interior (DOI) and the Office of Management and Budget (OMB) studied the problem in concert with the U.S Geological Survey (USGS) and called for decisive actions.

A major problem has been simply understanding the scope of Federal digital cartographic activities. Enough is known now, however, to begin work on coordinating multiple agency data needs and to begin the difficult task of developing data standards.

## THE EVOLUTION OF FEDERAL COORDINATION

In the late 1970s, the USGS began collecting Federal require-·ents for digital cartographic data and began coordinating digital cartographic activities on a technical information exchange basis in the Department of the Interior and with the U.S. Forest Service and the U.S. So'l Conservation Service. Following an appropriations request for a national digital cartography program, the OMB and the Office of Science and Technology Policy conducted a study which concluded (1) there was sufficient demand for a program, (2) the Federal Government

should be involved because the data would serve the public good, (3) management for the program should be vested in one place - USGS, and (4) the program should be operated on a cost recovery basis. Proposed legislation to establish a separate appropriation was introduced in the closing day of the Carter Administration. It was reintroduced in the Reagan Administration and referred to the Senate Subcommittee on Energy and Mineral Resources. Senator Warner, the Chairman of that committee, requested a GAO study. In November 1983, GAO published a report "Duplicative Federal Computer-Mapping programs: A Growing Problem" that recommended that OMB issue a circular or other directive requiring interagency coordination.

By this time, the Department of the Interior had already taken action. On October 22, 1982, the Secretary of the Interior signed a memorandum establishing the Interior Digital Cartography Coordinating Commmittee (IDCCC) and tasking the USGS to develop and manage a National Digital Cartographic Data Base. The IDCCC has been working for over a year and a half and is actively coordinating data requirements, data standards, and digital cartographic technical information in the Department of the Interior.

The need for standards had long been foreseen. In response to this need, USGS had provided a grant in March 1982 to the American Congress on Surveying and Mapping to bring together from private industry, academia, and the Federal Government, people who were active in digital cartography and were interested in developing standards. From that initiative, the National Committee for Digital Cartographic Data Standards, under the leadership of Professor Harold Moellering, Ohio State University, was formed.

On Arpil 4, 1983, David Stockman, the Director of the OMB, signed a memorandum establishing the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC) and tasked the Department of the Interior and the USGS to take the lead Federal role.

In response to the OMB memorandum, 57 representatives from 23 Federal agencies met at the U.S. Geological Survey on May 27, 1983, and formed the Federal Interagency Coordinating Committee on Digital Cartography.

The USGS, representing the Deparment of the Interior, chairs the FICCDC and its steering committee with departmental representation from Agriculture, Defense, Commerce, State, National Aeronautics and Space Administration, Housing and Urban Development, Energy, Transportation, the Federal Emergency Management Agency, and the Environmental Protection Agency.

The FICCDC steering committee has established the following working groups:

| FICCDC Working Groups | Functions |
|---|---|
| Reports | To monitor Federal computer mapping efforts in order to avoid duplication and ensure effective uses of digital cartography. To collect and maintain, |

| | |
|---|---|
| | and report summary information on agencies; digital data programs, including resources being expended. |
| Requirements | To identify Federal requirements for digital cartographic data and provide the coordination and priorities of collection to assist in ensuring that these needs are met. |
| Standards | To provide a mechanism for the development and review of digital cartographic data standards within the Federal Government that will facilitate data interchange and avoid or minimize unnecessary costs of conversions and incompatibilities. This includes the selection of the multipurpose data categories the USGS will collect, their standards and specifications. |
| Technology Exchange | To serve as a forum for exchange of information and ideas on technology and methods for collection, managing, and utilizing cartographic data. To monitor evolving technology and to identify areas in need of further research and development. |
| Applications | To facilitate the economic and efficient application of digital cartographic data. |

## MAJOR APPLICATIONS IN THE FEDERAL GOVERNMENT

### Cartographic Data in a New Form

While conventional hard copy maps form the foundation for various thematic data sets needed by government scientists, managers, and analysts, the hard copy medium limits the analytical techniques that can be applied to manipulate and analyze the data to mostly manual approaches. Map data in digital form, however, permit the use of automated analytical techniques to perfrom such tasks as accurately computing lengths of lines and areas of polygons. More complex spatial data handling techniques have been developed to compare many data sets rapidly against a set of predetermined criteria. This capability is proving invaluable where the speed of analysis is important and where many different sorts of data need to be considered.

### Major Applications

Following are a few of the major applications in the Federal Government:

- Department of Agriculture

  The Soil Conservation Service (SCS) uses digital cartographic data to support the following: local conservation planning-special soil acreage calculations' State and regional planning;

soils mapping-special slope and aspect maps from digital elevation models, and digitized soils maps land evaluation site assessment program; Watershed projects; and preparation of status maps.

The Statistical Reporting Service (SRS) is analyzing digital data from the multispectral scanner (MSS) and the thematic mapper (TM) to improve crop estimates.

The U.S. Forest Service (FS) is digitizing public land survey data and terrain data to automate the generation of orthophotos and as a tool for revising maps. They are also analyzing digital terrain data for road reconnaissance and design.

- Department of Commerce

The Bureau of Census has been using a digital file of urban areas, often referred to as the GBF/DIME (Geographic Base File/Dual Independent Maped Encoding) files. Beginning in FY 1983, the Bureau of the Census and the USGS initiated a large cooperative project to digitize transportation and hydrographic data from 1:100,000-scale maps. This new data base is planned for completion in 1987 and will be used by the Bureau of the Census to prepare enumerator maps for the 1990 census and to prepare special map products that accompany statistical reports resulting from the 1990 census. The data base so developed by cooperative efforts of the two agencies will form the basis for a large multipurpose data base available to all Federal agencies for a multiplicity of purposes.

The National Bureau of Standards (NBS) is responsible for standardizing the alphanumeric codes used to identify, locate, and relate data to geographic entities and is participating on a Federal Committee, that will be discussed later, to develop national standards for digital cartographic data.

The National Oceanic and Atmospheric Administration (NOAA

The Nautical Charting Division uses digital hydrographic data, digitized chart data, digital obstruction data for chart production and automated navigation systems.

The Aeronautical Division uses digital cartographic data, formatted in a graphic file or graphic network, to generate the NOA Controller Chart Supplement which portrays bearing and distances. The primary application is automating the compilation of aeronautical charts.

- Department of Defense

The Defense Mapping Agency (DMA) is using digital terrain data for mission planning, flight simulations and line-of-sight analysis. Although most of their activities are outside the United States, DMA is cooperating with the USGS to advance, through the private sector, the develop-

ment of new techniques that will automate the generation of smaller scale map products from larger scale digital cartographic data.

The U.S. Army Corps of Engineers (COE) is using many kinds of digital cartographic data including terrain, land use, building locations, utilities, boundaries, and transportation systems to develop master plans for military installations. The COE is also using digitized hydrologic data, land use data, and elevation data to assist in flood control management annd similar civil works activities.

- Department of Energy

The Department of Energy's (DOE) current applications of digital cartography support both research programs and applications. Typical of the research activities are such programs as: (1) atmospheric fluid dynamic analysis for predicting wind flow in complex terrain, (2) surface and subsurface hydrological transport processes, (3) geoscience analysis, (4) magnetics. Typical application includes: (1) environmental analysis of transmission facilities, (2) geologic and engineering planning, re: production of oil and gas, (3) locally developed site mapping, (4) analytical aerial triangulation to supplement ground control, and (5) preparation of base maps for bottom survey off American Samoa from existing surveys.

- Department of Housing and Development

The Department of Housing and Development (HUD) is using automated techniques to prepare thematic maps of the U.S. with counties shaded by data values and thematic maps of Standard Metropolitan Statistical Areas (SMSA) with census tracts shaded.

- Department of the Interior

The Bureau of Indian Affairs (BIA) is automating the analysis of digital land use, data soils data, elevation data, and related data to determine the optimum utilization of Indian lands for irrigation and other uses.

The Bureau of Land Management (BLM) is developing an automated land description and land status data base to replace the manual historical index and Master Titles Plat Records System. This system will contain data for approximately 46,000 townships and will be fully interactive for daily inquiries to update land records, process records for various land uses, and prepare graphics and reports on BLM lands.

The Bureau of Mines (BoM) is operating a digitized spatial data information system on the location of industry mineral data. They are also developing a capability to automate mineral reserve analyses on wilderness lands.

The U.S. Fish and Wildlife Service (F&WS) has developed the Map Overlay Statistical System (MOSS) to simultaneously evaluate a variety of themes about the land with particular emphasis on biological data. Through use of this geographic information system, the F&WS has been able to develop better refuge plans that consider the habitat needs of many wildlife species as well as other uses of the land. The MOSS system has been adopted for use by other Federal bureaus and by the State of Colorado.

The Minerals Management Service (MMS) uses an automated cartographic system to keep track of oil and gas operations on all Outer Continental Shelf leases under Federal jurisdiction.

The National Park Service (NPS) is automating the analysis of natural resource information to support planning and management of many national parks.

The Office of Surface Mining (OSM) is using digital terrain data to automate the computation of volumetric differences between pre-mining topography and anticipated post-mining topography prior to mine plan approval.

The U.S. Geological Survey (USGS)
Arc-second digital elevation data, 1:24,000-scale digital elevation models, land use and land cover data, and other planimetric data such as hydrography, geology, boundaries, precipitation and evaporation are used in digital form for extracting drainage basin characteristics to determine their hydrologic significance, for computing hydrologic balances, for aggregating boundaries, for determining geographic relationships, and for interpolating hydrologic values.

Elevation data; geologic maps; geophysical, geochemical and radiometric data; public land surveys; political boundaries; and extent of mined lands, and coal data are used in digital form to support geologic investigations. These data are merged, integrated, and modeled to assess mineral and mineral fuel resources in wilderness areas, geologic hazards (e.g., landslides), mineral deposit potential and coal resources and to support the National Coal Resource Data System (NCRDS), Mineral Resource Data System (MRDS), Mineral Resource Assessment System (MRAS), Conterminous U>S> Minerals Assessment program (CUSMAP), and Alaska Mineral Assessment program (AMRAP).

Digital cartographic data from USGS maps, remotely sensed data (Landsat multispectral scanner data and thematic mapper data and other types of digital geographic and cartographic data are used to support a variety of research programs dealing with data base development (digitizing, merging, classification, statistical analysis, modeling) and cartographic display (maps, overlays, tables, photo image). Applications projects include acid rain impact assessments (Environmental Protection Agency and National

Park Service), Interim Land Cover Mapping in Alaska (Alaska Federal and State agencies) and the Federal Mineral Land Information System.

USGS believes that the most important contribution that it is making to support Federal digital cartographic activities is the development of a National Digital Cartographic Data Base containing digital base data categories from the Survey's various national map series. A fuller discussion of this data base will occur later in this paper.

The Bureau of Reclamation (BuR) Digital cartographic data are used to generate radio path profiles in GIS analysis for land use and water resource development and in flood hydrology studies. Data types include arc-second digital elevation data, 1:24,000-scale digital elevation models, public land survey, land use/land cover, political boundaries, administrative boundaries, soil associations, soil salinity, and location of bore holes. These data are processed and analyzed to generate topographic profiles and flood hydrography and to assess current irrigation, irrigation suitability, and wildlife habitat. Much of this work involves the analyses of land use and detailed soil data for the purpose of determining the eligibility of farm land to receive Federal agricultural water service.

- Department of Transportation

The Federal Aviation Administration (FAA) uses fixed positional digital data describing air route structures, obstacles, navigation aids, and national airspace configurations. The data is used to produce displays for air traffic control system operations and in-flight navigational assistance. The data is produced for FAA through an interagency agreement with NOAA.

The Federal Railroad Administration maintains a current digitized representation of the complete U>S> railroad system and the rail defense essential network, for display and analysis of annual rail traffic flows on the network.

The U.S. Coast Guard uses nautical cartographic data in digital form for navigation of Coast Guard cutters in coastal waters and in harbors. The data, captured and digitized by the DMA for use in a new automated navigational system (Comdac), includes 18-foot shoal line, channel lines, coast lines, and all aids to navigation.

The Urban Mass Transportation Administration (UMTA). Applications of the UMTA include the development of a mathematical software model based on the U>S> Bureau of the Census Geographic Base File/Dual Independent Map Encoding (GBF/Dime) data structure which can be used to represent transportation networks (streets, fixed guideways). The research and development work is being accomplished through a cooperative agreement

with Santa Clara County, California, with joint funding. The mathematical model structure represents intersections, street segments, and land areas to which demographic, administrative and political data can be associated to produce networks displays and thematic maps for transportation planning and analysis purposes.

The Environmental Protection Agency (EPA). Maintains a digital data base of U.S. surface waters for identifying streams, lakes, reservoirs, estuaries, and their physical characteristics and uses this data base for water quality analyses and cartographic displays.

The Federal Communications Commission uses digital elevation data for radio propagation analyses.

The Federal Emergency Management Agency (FEMA) uses digital cartographic data to maintain and expand its realtime geocoded resources system. The automated system is used to support several agency missions; flood plain management, disaster management, and civil preparedness. Typical products of the system include base map displays of administrative and political boundaries associated with demographic and geographic data to produce thematic map displays. The agency also produced thematic maps at 1:100,000 scale (not published) for State and local agency use related to flood insurance assessment, nuclear reactor site evacuation planning, hurricane evacuation planning, and civil prepareness.

The National Aeronautics and Space Administration (NASA) is conducting research on digital terrain data collection techniques to support planetary exploration.

The Tennessee Valley Authority's (TVA) current applications of digital cartography include: (1) revision of 7.5-minute, 1:24,000-scale TVA topographic quadrangles, (2) production of special-purpose maps, e.g., U.S. Army Corps of Engineers-TVA Navigation Charts, Buoy Range Reference Maps, Nuclear Emergency preparedness Maps, (3) Prime Farmlands Mapping, (4) Generation of Site-specific Digital Terrain Models, and (5) Generation of Cross Section for Design and Flood Studies. Additionally, digital cartographic data are used as the basis for specialized graphics and analysis for the following activities: (6) Environmental Assessment and Monitoring, (7) Regional Site Screening, (8) Management of TVA Land, (9) Community Planning, (10) Socioeconomic Analysis, and (11) Resource Inventory.

The Agency for International Development (AID) is using digital Landsat data in image analysis systems to evaluate land use and natural resource in Peru and Thailand.

## Federal Expenditures

Federal agencies reported total FY 1984 expenditures of $104 million of which over $74 million was spent for applications

of digital spatial data (Table 1, p. 8), $10 million was spent to produce base categories of digital cartographic data (U.S. Geological Survey and National Ocean Survey) (Table 2), $9 million was spent to produce digital thematic data (Table 3), over $5 million was spent on software (Table 4), and nearly $6 million was spent on hardware (Table 4). It is clear that Federal expenditures are somewhat larger because financial data was not provided for many reported activities, and some known activities were not reported.

## BASE MAP DATA CATEGORIES - A UNIFYING FRAMEWORK

There has been a large and growing demand for digitized base map data categories to form a reference for linking various thematic data sets. To meet this demand, the USGS began digitizing base map categories from its various national map series. Following is a list of the scales and types of digital cartographic data presently being collected for the National Digital Cartographic Data Base.

Table 2: Data Types in the National Digital Cartographic Data Base

| Scale Series | Product (Data Type) |
|---|---|
| 1:24,000 | A. Digital Elevation Model |
| | B. Digital Line Graph<br>Land Net<br>Boundaries<br>Transportation<br>Hydrography |
| 1:100,000 | Transportation<br>Hydrography |
| 1:250,000 | Land Use/Land Cover (Polygon)<br>Census Tracts<br>Political Boundaries<br>Hydrologic Units<br>Federal Land Ownership<br>Composite (Grid Cell)<br>Geographic Names by State |
| 1:250,000 | Digital Terrain Data ($1^{\circ} \times 1^{\circ}$ Blocks produced by DMA) |
| 1:2,000,000 | Digital Line Graph<br>Boundaries<br>Transportation<br>Hydrography |

## THE TASK AHEAD: CHALLENGES FOR COORDINATION

Coordination of a new and rapidly developing technology like digital cartography is a considerable challenge. It is difficult for all participants to be at the same level of awareness

and knowledge. Further, the rapid changes in technology mean that great care must be taken in the establishment of standards to avoid their becoming obsolete or irrelevant. To meet these challenges, the coordination effort is being defined in terms of four main objectives with specific tasks undertaken to work toward achievement of the objectives. The objectives are:

- Avoid duplication and waste
- Facilitate the exchange of data
- Establish common standards for multipurpose data
- Promote the development and application of digital cartography

In order to reach these objectives, a variety of tasks are being undertaken. One of the first tasks was to develop an inventory of digital cartographic activities in the Federal Government. This yielded an understanding of current capabilities, types of work being performed, kinds of data collected, and standards used. This effort is complete and a report was forwarded to OMB in September 1984. Knowledge of such baseline information will aid in avoiding duplication and serve to guide further coordination. Another task is to establish and enhance communication networks. Effective coordination requires efficient communication. Meetings of committees and working groups, presentations at professional meetings, briefings of interested groups will all contribute to an improved flow of information. In addition, a newsletter is being established that will serve as a forum for digital cartography in the Federal Government.

One of the critical needs is for the establishment of standards for use by the community. The USGS has signed a Memorandum of Understanding with the National Bureau of Standards that assigns USGS the lead role for the development of Earth Science data standards including digital cartography. In the fall of 1983, the USGS began publishing the standards used for collecting data or the National Digital Cartographic Data Base. This document, U.S. Geological Survey Digital Cartographic Data Standards, is published as Circular 895. The following chapters are available:

USGS DIGITAL CARTOGRAPHIC DATA STANDARDS

USGS Circular 895 -

- A: Overview and USGS Activitives
- B: Digital Elevation Models
- C: Digital Line Graphs from 1:24,000-Scale Maps
- D: Digital Line Graphs from 1:2,000,000-Scale Maps
- E: Land Use and Land Cover Digital Data
- F: Geographic Names Information System
- G: Digital Line Graph Attribute Coding Standards

These will be reviewed through the various coordinating mechanisms and, following comment and revision, will be submitted for Federal standards for base category digital cartographic information.

A major effort on standards development is now underway through the National Committee for Digital Cartographic Data Standards (NCDCDS) chaired by Professor Harold Moellering. There is very close liaison between the National Committee for Digital Cartographic Standards and the Federal Interagency Coordination Committee on Digital Cartography. Much of the standards work of the Federal agencies will be based upon the foundation laid by the NCDCDS. Standards will be developed in a phased approach beginning with those having the highest priority, i.e., those with the largest number of users. The first step will be to make documentation available, in draft form, for existing data and then to refine those into standards through the appropriate working group. The key aspects covered by the standards will be accuracy, content, and format. The emergence of such standards will benefit all four objectives and be of considerable value to the entire community of users.

## SUMMARY

Advances in the mapping sciences are altering significantly the ways in which maps can be prepared, stored, and used. A major problem in coordination has been simply understanding the scope of Federal digital cartographic activities. We have learned that Federal digital cartographic activities are large, widespread, and growing.

The USGS is dedicated to coordinating Federal digital cartographic activities. To meet this challenge the coordination objectives are:

- Avoid duplication and waste
- Facilitate the exchange of data
- Establish common standards for multipurpose data
- Promote the development and application of digital cartography

To reach these objectives, the Federal Interagency Coordinating Committee has conducted a comprehensive inventory of the kinds of data being collected and standards used. Knowledge of this baseline data is essential to guiding further coordination. We are going to enhance communication through working groups and by establishing a newsletter that will serve as a forum for digital cartography in the Federal government.

Most importantly, we have begun the difficult task of developing data standards by fostering the National Committee for Digital Cartographic Data Standards with representation from private industry, academia, and the Federal Government and we intend to build on that effort through the Federal Interagency Coordinating Committee on Digital Cartography.

TABLE 1

ESTIMATED FY 1984 EXPENDITURES FOR APPLICATIONS

| | FY 1984 ($000) | FY 1985 ($000) |
|---|---|---|
| Total | 74,485 | 72,045 |
| Department of Agriculture | 900 | 1,000 |
| Forest Service | 400 | 500 |
| Soil Conservation Service | 500 | 500 |
| Department of Commerce | 360 | 360 |
| Census | Not reported | Not reported |
| Bureau of Standards | Not reported | Not reported |
| National Ocean Service | 360 | 360 |
| Department of Defense | 54,700 | 54,700 |
| Defense Mapping Agency** | 48,000 | 48,000 |
| U.S. Corps of Engineers | 6,700 | 6,700 |
| Department of Energy | 2,827 | Not reported |
| Housing and Urban Development | Not reported | Not reported |
| Department of the Interior | 5,715 | 5,600 |
| Bureau of Mines | Not reported | Not reported |
| Minerals Management Service | Not reported | Not reported |
| Office of Surface Mining | - | - |
| Fish and Wildlife Service | 900 | 700 |
| National Park Service | 500 | 500 |
| Bureau of Indian Affairs | 500 | 500 |
| Bureau of Land Management | 700 | 700 |
| Bureau of Reclamation | 115 | 200 |
| Geological Survey | 3,000 | 3,000 |
| National Aeronautics and Space Administration | NO REPORT | NO REPORT |
| Department of State | - | - |
| Department of Transportation | 4,675 | 4,765 |
| Federal Aviation Administration | Not reported | Not reported |
| Federal Highway Administration | - | - |
| Federal Railroad Administration | 100 | 100 |
| Res. & Spec. Programs Admin. | Not reported | Not reported |
| Trans. Systems Center | - | - |
| U.S. Coast Guard | 4,500 | 4,500 |
| Urban Mass. Trans. Admin. | 75 | 165 |
| Environmental Protection Agency | 250 | 250 |
| Federal Emergency Management Agency | 200 | 400 |
| Tennessee Valley Authority | 358 | 470 |
| U.S. Agency for International Development | 4,500 | 4,500 |

* Does not include research and development or data collection expenditures.
** Includes worldwide applications

TABLE 2

DATA COLLECTION FOR NATIONAL MAPPING AGENCY PRODUCTS

| DATA TYPE | NATIONAL MAPPING AGENCY PROGRAM | | | OTHER AGENCIES' PROGRAM | | | TOTAL PROGRAM | |
|---|---|---|---|---|---|---|---|---|
| | NMA Data Collection Costs $(000) | | No. Federal Agencies Using NMA Data | No. Federal Agencies Collecting NMD Data Types | Collection Costs ($000) | | Total ($000) | |
| Map Series and Layers | FY 84 | FY 85-86 | | | FY 84 | FY 85-86 | Spent FY 84 | Projected FY 85-86 |
| USGS 7.5' 1:24,000 | | | | | | | | |
| - PLSS | 570 | 850 | 8 | 9 | 118 | 175 | 688 | 1,025 |
| - Boundaries | 570 | 850 | 8 | 10 | 99 | 114 | 669 | 964 |
| - Transportation | 330 | 650 | 6 | 8 | 129 | 202 | 459 | 852 |
| - Hydrography | 330 | 650 | 6 | 9 | 126 | 334 | 456 | 984 |
| - DEM | 2,200 | 4,000 | 11 | 8 | 607 | 474 | 2,807 | 4,474 |
| - Other | | | | 12 | 193 | 421 | 193 | 421 |
| | 4,000 | 7,000 | | | 1,272 | 1,720 | 5,272 | 8,720 |
| USGS Intermediate 1:100,000 Scale | | | | | | | | |
| - Transportation | 2,150 | 8,800 | 4 | 4 | 21 | 250 | 2,171 | 9,050 |
| - Hydrography | 2,150 | 8,800 | 4 | 2 | | | 2,150 | 8,800 |
| - Other | | | | 5 | 102 | 55 | 102 | 55 |
| | 4,300 | 17,600 | | | 123 | 305 | 4,423 | 17,905 |
| USGS National Atlas 1:2,000,000 | | | | | | | | |
| - Boundaries | | | 9 | 5 | 9 | 15 | 9 | 15 |
| - Transportation | | | 8 | 3 | 9 | 10 | 9 | 10 |
| - Hydrography | | | 8 | 3 | 9 | 10 | 9 | 10 |
| - Other | | 75 | | 4 | 6 | 27 | 6 | 102 |
| | | 75 | | | 33 | 62 | 33 | 137 |
| All Other USGS | 450 | 900 | 9 | 9 | 576 | 985 | 1,026 | 1,885 |
| SUBTOTAL USGS | 8,750 | 25,575 | | Subtotal Other Agencies | 2,004 | 3,072 | 10,754 | 28,647 |
| NOS Hydro-Surveys | 1,000 | 2,000 | 3 | 4 | 35 | 72 | 1,035 | 2,072 |
| NOS Obstruction Data | 200 | 400 | 1 | | | | 200 | 400 |
| Other Aeronautical Data | | | | 1 | 4 | 8 | 4 | 8 |
| SUBTOTAL NOS | 1,200 | 2,400 | | SUBTOTAL OTHER AGENCIES | 39 | 80 | 1,239 | 2,480 |
| TOTAL NMA's | 9,950 | 27,975 | | TOTAL OA's | 2,034 | 3,152 | 11,993 | 31,127 |

TABLE 3

REPORTED FY 1984 COSTS FOR THEMATIC LAYER DIGITIZING

| Agency | $(000) In-House Expenditures | % Total | $(000) Contract Expenditures | %Total | $(000) Total Expenditures |
|---|---|---|---|---|---|
| COE | $ 509 | 31 | $1,107 | 69 | $1,616 |
| FEMA | 0 | 0 | 1,450 | 100 | 1,450 |
| FS | 1,351 | 93 | 97 | 7 | 1,448 |
| USGS | 726 | 84 | 134 | 16 | 860 |
| NOS | 811 | 100 | 0 | 0 | 811 |
| FWS | 82 | 10 | 717 | 90 | 799 |
| SCS | 335 | 50 | 330 | 50 | 665 |
| BLM | 372 | 70 | 160 | 30 | 532 |
| Others (8) | 521 | 87 | 75 | 13 | 596 |
| TOTALS | $4,707 | 54% | $4,070 | 46% | $8,777 |

TABLE 4

FY 1984 EXPENDITURES FOR SPATIAL DATA HARDWQRE AND SOFTWARE

| Department/Agency | Software Development/Procurement $(000) | Additional | Hardware Development/Procurement $(000) |
|---|---|---|---|
| Agriculture | | | |
| Soil Conservation Service | $50 | | $150 |
| Forest Service | $145 | | - |
| Commerce | | | |
| National Ocean Service | - | | $1,800 |
| Bureau of the Census | $1,177 | | - |
| Bureau of Standards | - | | - |
| Defense | | | |
| Defense Mapping Agency | $1,396 | ($625,000--FY 84 studies) | $445 |
| Corps of Engineers/ETL | $1,887 | | $2,937 (consolidated) |
| Energy | Not reported | | Not reported |
| Housing and Urban Development | | | |
| Interior | | | |
| Bureau of Mines | | | |
| Minerals Management Service | | | |
| Office of Surface Mining | | | |
| Fish & Wildlife Service | $164 | | - |
| National Park Service | - | | - |
| Bureau of Indian Affairs | | | |
| Bureau of Land Management | $152 | | $359 |
| Bureau of Reclamation | | | |
| Geological Survey | $106 | | $40 |
| State | - | | - |
| Transportation | | | |
| Federal Aviation Agency | | | |
| Federal Highway Administration | | | |
| Federal Railroad Administration | $160 | | - |
| Research and Special Programs | - | | - |
| Transportation Systems Center | | | |
| U.S. Coast Guard | - | | - |
| Urban Mass Transportation Administration | | | |
| Independent Agencies | | | |
| Federal Emergency Management Agency | | | |
| Environmental Protection Agency | | | |
| National Aeronautics & Space Administration | | | |
| Tennessee Valley Authority | - | | - |
| Agency for International Development | $125 | | $4,900 (consolidated) |
| TOTAL | $5,362 | | $5,731 |

ANNUAL MAPPING AND CARTOGRAPHIC DATA REQUIREMENTS

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Abstract

The U.S. Geological Survey's (USGS) National Mapping Division annually solicits mapping and digital cartographic data requirements from State and Federal agencies. When the Office of Management and Budget's (OMB) predecessor, the Bureau of the Budget, formalized this process three decades ago through its Circular A-16, USGS was providing the map user community only with very basic types of map products, and most efforts became focused on 1:24,000-scale, 7.5-minute topographic quadrangle maps. In the last decade (or so) a more sophisticated map user community has gradually demanded a wider range of map products, and is demanding many of these map products in digital form. The USGS now produces intermediate scale maps at 1:100,000-scale, topographic and topographic/bathymetric editions of the 1:250,000-scale map series, land use/land cover maps in graphic and digital form, and provides base categories of map data, such as public land survey system and boundary features, in standard digital formats. Orthophotoquads are now produced as companion products for many 1:24,000-scale topographic maps, and the need for image map products at several scales is emerging rapidly. USGS is coordinating Federal needs for high altitude photography, both black-and-white and color infrared, to stretch the Federal dollar and ensure cyclic national coverage.

This diversity in the National Mapping Program, and the inherent interdependency between these individual mapping programs, has heightened the Survey's need to better understand and plan in order to be responsive to rapidly changing map user requirements. Annual A-16 letters are still sent to all Federal Agencies to solicit their needs but the Survey realizes that what is needed now is a more continuing dialogue with map users which includes individual agency reviews of what products have been requested, what priorities those requests have in the current programs, an assessment of when USGS can respond to some of the requests that couldn't be incorporated in the current programs, and a chance to discuss emerging requirements, for both existing or new map products.

Inquiries regarding the mapping programs of the USGS should be addressed to: John L. Greenwald, Chief, Office of Plans and Coordination, U.S. Geological Survey, National Mapping Division, Reston, VA 22092 (Tele. 703-860-6214; FTS 928-6214).

The U.S. Army Corps of Engineers contact for liaison on the National Mapping Program is M. K. Miles, Civil Engineer, DAEN-ECE-BX, 20 Massachusetts Ave., NW, Washington, D.C. 20314 (Tel: 202-272-0216).

Following are highlights from major components of the National Mapping Program:

Primary Mapping

- o At the end of FY 1984, 84 percent of the 7.5-minute maps required to cover the conterminous United States and Hawaii were published, and 90 percent of the 15-minute maps for Alaska were published.

- o Complete national coverage of the U.S. with 7.5-minute and 15-minute (Alaska) primary maps is projected for FY 1989.

- o To expedite 7.5-minute and 15-minute map coverage, the USGS introduced the provisional map concept in 1981. Provisional maps contain about the same level of information as the standard maps, but with lmited map finishing.

- o Because all new mapping has been authorized for production, no requirements were requested from Federal agencies.

Revision Mapping

- o About 1,300 maps per year are revised as photorevisions, limited revisions, and complete revisions. This effort represents about 40 percent of candidate maps inspected.

- o Photorevision constitutes about 90 percent of the total revision effort.

- o After 1989 revision efforts will be increased significantly.

Orthophotoquad Mapping

- o Orthophotoquad coverage (7.5-minute quad format) for conterminous United States and Hawaii is about 60 percent.

- o Orthophotoquad's for major areas of Alaska are in production (15-minute quad format) in response to Bureau of Land Management requirements to support the Alaska Native Claims Settlement Act of 1971 and the Alaska National Interest Lands Conservation Act of 1980.

- o Simulated natural color 1:25,000-scale orthophotoquads of the US/Mexico international boundary are being prepared in cooperation with the U.S. Customs Service. As of the end of FY 1984, over 60 of these 215 border-centered image maps have been published.

Landsat Image Mapping

- o Several 1:250,000-scale image maps are now in production as a companion to the map series of the same scale.

- o Twenty-five experimental image maps at 1:250,000 scale were prepared to support the Federal Government's Alaska oil and gas program.

- Recently the Landsat-4 TM Washington, D.C. and Vicinity Image Map at 1:100,000 scale was published to demonstrate the system's high-resolution capability.

Intermediate-Scale Mapping

- Intermediate-scale products include maps in both quadrangle and county formats at scales of 1:50,000 and 1:100,000.

- The principal intermediate-scale is the 1:100,000-scale metric topographic quadrangle map consisting of up to 23 feature separates which can be selectively combined to produce derivative maps with varying levels of content.

- Published USGS topographic editions are available for over 700 1:100,000-scale quads, out of a conterminous U.S. total of 1800. The remaining quads will be completed as planimetric editions by the end of 1986, under an interagency agreement with Bureau of the Census. In 1987-90, we will work to complete remaining topographic editions.

Small-Scale Mapping

- The 1:250,000-scale map series provides the largest scale topographic map coverage for the entire United States. USGS annually revises about 40 of the 627 maps in this series.

Topographic/Bathymetric Maps

- The USGS portrays available National Ocean Service (NOS) bathymetric on one quadrangle maps at 1:24,000-, 1:100,000-, and 1:250,000-scale. To date 166 topographic/bathymetric at the various scales have been published by USGS; the maps are distributed by both USGS and NOS. The goal of this effort is to complete about 50 maps per year.

Land Use and Land Cover Mapping Program

- Open file land use and land cover (LU/LC), and associated maps are available for 80% of the conterminous U.S. and Hawaii. About 40 maps, primarily at 1:250,000-scale, are completed annually. Completion of conterminous U.S. and Hawaii graphic coverage is planned for FY 1986; we a e examining requirements for an update program.

- Digital LU/LC data in vector and grid cell format are available for 50% of the conterminous U.S. and Hawaii. Digital data is now produced at about the same rate as graphic products. Completion of digital LU/LC data for the conterminous U.S. and Hawaii is planned for 1990.

## Digital Cartography

- The USGS is developing a National Digital Cartographic Data Base (NDCDB) as part of its responsibilities under its Federal leadership role in digital cartography.

- Under a joint USGS/Bureau of the Census work share program, transportation and hydrographic data are being digitized from the 1:100,000-scale map series to support the 1990 Decennial Census.

- Other digital cartographic activities include the digitizing of elevation data, public-land survey data, boundaries, hydrography, and transportation data from the 1:24,000-scale maps.

- Boundaries, transportation, and hydrographic digital data sets from the 1:2,000,000-scale general reference regional maps of the "National Atlas of the United States" are available in topologically-structured format and also in a format for preparing graphics.

- During FY 1983 and 1984 the USGS published Circular 895 - "USGS Digital Cartographic Data Standards" for digital elevation models, 1:24,000-scale digital line graphs, 1:2,000,000-scale digital line graphics, land use and land cover digital data, and the geographic names information system. Other chapters will be added to include additional data products, such as the 1:100,000-scale map data.

## National High Altitude Photography (NHAP) Program

- The NHAP program is a multi-agency Federal effort to establish a National High Altitude Photography Data Base consisting of 1:80,000-scale black-and-white (B/W) and 1:58,000-scale color infrared (CIR) photography and to make the photography available to all users, public and private.

- The USGS has the lead coordination and contracting role and shares with twelve other participating agencies the responsibility for funding the acquisition of the photography.

### NHAP-I

- Started in FY 1980 to acquire HAP during the dormant (leaf-off) season.
- Entire conterminous U.S. under contract.
- Photography acquired for approximately 75 percent of 48 States and is available to all users from EDC or ACSC.
- The Corps of Engineers has not been a participant (funding agency) but the Corp's New Orleans Office has funded the acquisition of NAP over Mississippi River area in Louisiana in FY 1984 to meet needs of special study.
- Anticipate completion of NHAP-I about the end of CY 1986.

NHAP-II

- o Five to six-year program will begin in FY 1985 in the States of Alabama, Kansas, Mississippi, and Tennessee.
- o HAP will be acquired during the growing season (leaf-on) and photography will be contracted by complete State units. Photo sales will remain the same.

National Atlas Program

- o First edition of the "National Atlas" of the United States (bound-417 pages map, text, gazetteer) published by USGS in 1970; by 1976 all copies were sold.

- o Current short-term goals (2 year): Prepare and publish a 36-map sheet interim edition of the Atlas by the end of FY 1986 implementing the use of digital cartographic data and production techniques.

- o Long-term goals (5-10 year): Establish a National Atlas Geographic Information System as the primary source for current accurate information on the nation; prepare remainder of 200 map sheet second edition and other products.

- o Approximately 1/3 (12 map sheets) of interim edition in work. Topics include relief, vegetation, railroads, highways, ports and waterways, coastal hazards, etc.

- o Three map sheets completed and in final proof: Karst, Surficial Geology, National Ecological Research Areas.

- o USGS anticipates contacting COE for assistance in updating energy transportation maps, and maps showing port traffic and navigable waterways.

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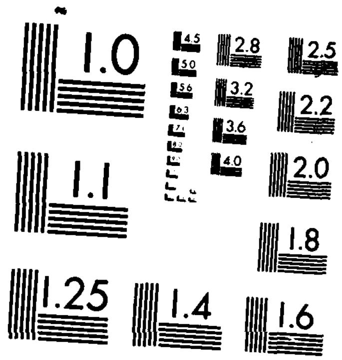


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

PERSONNEL AND EQUIPMENT

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NOTE: H - hydrographic.
T - topographic.

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